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TECTONIC CLASSIFICATION OF OIL FIELDS IN THE UNITED STATES[1]

WALTER A. VER WIEBE[2]
Wichita, Kansas

ABSTRACT

Up to the present it has been customary to group the oil fields of the United States according to geographic location. Facts brought out by intensive geological work of petroleum geologists during the last decade make it evident that the architecture of the continent has exercised the controlling influence over distribution of oil-producing areas. Petroliferous provinces should be named according to the tectonic element with which they are associated. The writer therefore groups the oil fields into eleven provinces: (1) Appalachian geosyncline, (2) Cincinnati arch, (3) Eastern Interior coal basin, (4) Michigan basin, (5) Western Interior coal basin, (6) Ouachita-Amarillo Mountain, (7) Bend arch, (8) Gulf embayment, (9) West Texas basin, (10) Rocky Mountain geosyncline, and (11) Pacific geosyncline. Some of these are subdivided into districts on the basis of subordinate structural features. The writer describes each province as to location, included fields, characteristics of each, such as age of producing horizons, lithologic character of horizons, tectonic elements and structural features of the second and third order, and relation of production to structure. In conclusion, the outstanding features of the provinces are recapitulated on a comparative basis in order to show that the age and nature of the producing horizons can not be used as a criterion, or the relation between structure and production, that the peculiar *structural habit* of a province can be used with certain limitations, but that the best criteria are the structural elements of the first order.

Regions in which the petroleum accumulations are related genetically and in which the geologic surroundings are closely similar were called "petroliferous provinces" by Woodruff.[3] The regions designated

[1]Presented before the Association at the Fort Worth meeting, March 22, 1929. Manuscript received by the editor, February 23, 1929.

[2]University of Wichita.

[3]E. G. Woodruff, "Petroliferous Provinces," *Amer. Inst. Min. Met. Eng. Bull.* *150* (1919), pp. 907-12.

by him as constituting provinces contain oil fields which have many characteristics in common, and in the light of the information then available represent the best classification that could be made. The truly remarkable record of geological details uncovered by petroleum geologists during the last decade makes possible some refinements in the classification, which are presented in this paper.

TECTONIC ELEMENTS IN THE UNITED STATES

The best known tectonic element on the North American continent is the Appalachian geosyncline. It existed from pre-Cambrian time until the end of the Paleozoic era, but its borders and outlines changed considerably during that time. The negative area of which it formed the easternmost and most rapidly subsiding part, extended far beyond the Cincinnati anticline and merged with the area of the Mississippian sea. This condition continued until Middle Ordovician time, when differential subsidence created the positive element which later became the Cincinnati geanticline. Thereafter its borders were more stable and it extended as a group of troughs from Alabama to New York. The troughs were at no time very deep; hence conditions for the generation and accumulation of petroleum existed almost continuously from Ordovician to Permian time.

The areas of subsidence and the geosynclines west of the Appalachian geosyncline are less well known. In Michigan a nearly circular basin existed from late Cambrian or early Ordovician time to the end of the Paleozoic era. This area received sediments during all that time in waters which were shallow, as indicated by ripple marks and other criteria in the present consolidated rocks. It also received much organic matter from time to time, depending on climatic conditions, because we find black shales rich in organic matter at a number of stratigraphic horizons.

A somewhat more elongate basin existed at almost the same time as the Michigan basin in the states of Indiana, Illinois, western Kentucky, eastern Missouri, and Iowa. This basin has been named the Eastern Interior coal basin. It also was the site of deposition for shallow-water sediments and organic material. These materials accumulated from Middle Ordovician time throughout the Paleozoic era well into the Pennsylvanian period. During the Mississippian and Pennsylvanian periods climatic conditions for the generation of petroleum deposits were most favorable.

The next area of subsidence on the west which may be treated as a unit has been called the Cordilleran geosyncline.[1]

The negative area, of which the geosyncline proper is the deepest and most rapidly subsiding part, extended from the longitude of the present Mississippi River as far west as the land mass of Cascadia and from the Arctic Ocean on the north into Mexico on the south. During middle Paleozoic time differential subsidence brought into prominence parts which later became defined as positive areas. The most important of these positive areas has been called the Cordilleran intermontane geanticline, which reached its fullest development and greatest height probably in Jurassic time.

In the succeeding Cretaceous period, therefore, we find two negative areas within the confines of the original Cordilleran geosyncline province. The eastern of these was named the Rocky Mountain geosyncline,[2] and the western, the Pacific geosyncline.[3] The negative area of which the Rocky Mountain geosyncline is the most characteristic part extended from the Arctic Ocean south through the United States into Mexico. Its eastern border was marked by such positive elements as the Wisconsin dome, the St. Francois dome in southeastern Missouri, and the old continent of Llanoria, and its western limits were marked by the Cordilleran intermontane geanticline. Deposition took place in this large basin during Paleozoic time as well as during Mesozoic time. However, though the Paleozoic sediments are to be found in the whole basin, the Mesozoic sediments occupy only the western part of the basin. This fundamental difference in the age of the rocks makes necessary a separation of the two parts, as is explained later.

In the southern part of the United States are two basins which have not received as much attention from geologists as the basins farther north. Therefore our information regarding these basins is based largely upon the findings of petroleum geologists who have worked in that region during the last ten years or more. One of these basins is the Gulf embayment geosyncline (also called the Mississippi embayment) which was a part of the original Gulf of Mexico tectonic element. It may have been in existence since pre-Cambrian time, but much evidence indicates that it began its history in the Comanche period. The other basin in this part of the United States lies in western Texas and has been called the Permian basin or the West Texas basin.

[1]Charles Schuchert, "Sites and Nature of the North American Geosynclines," *Bull. Geol. Soc. Amer.*, Vol. 34 (1923), pp. 184-86.

[2]Charles Schuchert, *ibid.*

[3]*Idem.*

POSITIVE ELEMENTS

The tectonic elements already described are termed negative elements because during the time of their existence they subsided with reference to surrounding areas. Although they are more important from the standpoint of localizing petroliferous areas, some of the positive tectonic elements also have oil fields associated with them and must therefore receive consideration. The best known positive element is the Cincinnati anticline (geanticline or arch). It is the dividing ridge between the Appalachian geosyncline (in the larger sense) and the Eastern Interior coal basin. This arch first became important in Middle Ordovician time, when the Jessamine and Nashville domes remained above water while the surrounding areas continued to subside and receive deposition.

Another positive tectonic element, which is interesting to the petroleum geologist even though no petroleum fields have been found in it, is the St. Francois-Ozark area in southern Missouri and northern Arkansas. This area also became prominent first during Middle Ordovician time, although there is some evidence that the eastern part, called the St. Francois Mountains, was a positive feature from pre-Cambrian time. The core of this area has remained above water since its first emergence, but the flanks were submerged at intervals during succeeding periods of the earth's history. A very interesting buried extension of the Ozark dome has been called the Chautauqua arch by White, and the Ozark arch by Levorsen. It is in southern Kansas and northern Oklahoma and either connects with a north-south trending element or forms an arc in Kay County, Oklahoma, whence it continues south through the center of Oklahoma and connects with the Gend arch in Texas. This arcuate part of the extension was submerged in Mississippian and Pennsylvanian seas.

In southern Oklahoma the arcuate extension intercepts an east-west positive element which has been termed the Ouachita- Arbuckle-Wichita-Amarillo Mountain trend. It is a rather narrow element beginning in central Arkansas and extending through southern Oklahoma westward into the Panhandle of Texas. The eastern half of this element has had a somewhat more complicated geological history than the western half, but as a whole forms a very logical unit. The western end seems to have remained above water throughout Paleozoic time until late in the Pennsylvanian period, whereas the more eastern parts were submerged during the early part of the era and again, after a time of emergence, during the latter part of the era. This tectonic element separates the oil fields

of the eastern side of the Rocky Mountain basin from the fields of the Gulf embayment province and the fields of the West Texas basin.

The Bend arch is a well-known tectonic element in north-central Texas which also became a positive element in Middle Ordovician time. It may be considered an extension of the Llano-Burnet uplift of central Texas similar to the extension of the Ozark uplift described in the preceding paragraph. It became submerged in the Mississippian period and remained so, with minor interruptions, until well into the Permian period.

Very nearly on the same trend as the Bend arch and its probable continuation in Oklahoma lies the Granite Ridge of Kansas (Nemaha Mountain ridge). It is difficult to decide from the data available whether the fundamental controlling tectonic lines are the north and south lines indicated by these positive elements or whether the lines trending more nearly east and west were dominant. Both are no doubt intimately related to fault zones in the basement complex.

PETROLIFEROUS PROVINCES

A careful study of the oil fields of the United States shows that they are grouped naturally around the borders of the great basins or negative elements. Some are on, or closely adjacent to, the axes of the positive elements which are located between the basins. It seems appropriate, therefore, to name the provinces after the tectonic element to which they are most closely related. This system of classifying the fields has been followed in Table I, with very few exceptions. For example, the east side of the Rocky Mountain basin has fields which derive their oil mainly from Paleozoic rocks, and those on the west side of the basin derive their oil mainly from Mesozoic rocks. In choosing names for the provinces an attempt was made to choose names which had been used previously for the area affected so that any geologist would know immediately what part of the continent was referred to. In accordance with that principle the name Western Interior coal basin was chosen, because it brings to mind eastern Oklahoma and southeastern Kansas.

In some of the provinces as outlined in the table, it is necessary to make a subordinate grouping because of structural conditions which separate the province into individual, distinctive units. These units are called districts. In the Gulf embayment province, for example, there are four districts. Two of these may soon merge to form one (the Balcones fault district and the Reynosa escarpment district) because the characteristics of both are similar and new fields are being discovered between

TABLE I

TABLE OF PETROLIFEROUS PROVINCES

Province	*District*	*Area Involved*
Appalachian geosyncline		New York, Pennsylvania, West Virginia, eastern Ohio, eastern Kentucky
Cincinnati arch	Lima-Indiana	Western Ohio, eastern Indiana
	Cumberland saddle	South-central Kentucky, north-central Tennessee
	Alabama-Mississippi	Alabama, Mississippi
Eastern Interior coal basin		Northwestern Kentucky, Illinois, southwestern Indiana
Michigan basin		Michigan
Western Interior coal basin		Kansas, northern Oklahoma
Ouachita-Amarillo mountain	Arbuckle-Wichita	Southern Oklahoma
	Red River	North-central Texas
	Amarillo Mountain	Texas Panhandle
Bend arch		North-central Texas
Gulf embayment	Balcones fault	Eastern Texas
	Reynosa escarpment	Southern Texas
	Sabine-Ouachita uplifts	Northern Louisiana, southern Arkansas
	Salt dome	Southern Texas, southern Louisiana
West Texas		Western Texas, southeastern New Mexico
Rocky Mountain geosyncline	Big Horn basin	Wyoming, Montana
	Wind River basin	Wyoming (central)
	Green River basin	Southwestern Wyoming, northwestern Colorado
	Laramie basin	Southeastern Wyoming
	Powder River basin	Northeastern Wyoming
	Sweetgrass arch	Northern Montana
	Big Snowy anticlinorium	Central Montana

TABLE I—*Continued*

Province	*District*	*Area Involved*
	Julesburg basin	Eastern Colorado
	Uinta basin	Northwestern Colorado, northeastern Utah
	San Juan basin	Northwestern New Mexico
		Utah
Pacific geosyncline	San Joaquin valley	California
	Santa Maria	California
	Ventura	California
	Los Angeles basin	California

them which will serve to link them together. The other two districts in that province are so different that a distinction will always be necessary. The Rocky Mountain geosyncline province is divided into districts each of which is a small basin and possibly separated from the others by great distances. Yet all these districts have certain common characteristics so that they should be grouped together. The same may be said of the four districts in the Pacific geosyncline basin (Fig. 1).

Within a district there may be one pool or field, or many. The words *pool* and *field* are used more or less interchangeably in the literature. Petroleum geologists should agree to use these names in a specific sense. The writer suggests that the word *pool* be restricted to the smallest unit into which a petroliferous province could be divided and should refer to a number of wells forming a nearly uninterrupted group. The word *field* should be used for several pools or an area larger than the average pool and characterized by dry spots or zones.

APPALACHIAN GEOSYNCLINE PROVINCE

The fields of the Appalachian geosyncline comprise a unit, geologically and geographically. They are located in the states of New York, Pennsylvania, West Virginia, Kentucky, and Ohio. Only the eastern half of Ohio and the eastern quarter of Kentucky are included in the province. Because of the age of the fields and the great number of wells which have been drilled, we are exceptionally well acquainted with the characteristics of the province. The basin as a whole extends from the old land mass of Appalachia on the east to the Cincinnati anticline on

FIG. 1.—Map of United States showing petroliferous provinces.

the west and from Lake Ontario on the north to the northwestern part of Alabama on the south. Oil or gas pools occur throughout the included area with the exception of the highly-folded eastern zone. Of course there are some large areas in which no production has been found, but the distribution of oil throughout the province is remarkable.

In the geological history of the province the middle of the Ordovician period stands out as one of the critical points of time. The first pronounced effects of the diastrophic movements which influenced this province during the Paleozoic era evidently occurred then. Great shear planes were developed and overthrusts were produced in the thick limestones of the Cambrian and Ordovician succession of strata. Keith[1] has described such features which antedate the folding and are themselves thrown into anticlines and synclines. The middle of the Ordovician period also marks the first time of petroleum formation and accumulation in the province (notwithstanding that some gas has been found stratigraphically lower). The great climax of diastrophic movements came during Pennsylvanian time and probably persisted through Permian time. It was then that the long, nearly parallel anticlines and synclines were produced which are so characteristic of the province.

[1]A. Keith, "Roan Mountain Folio," *U. S. Geol. Survey Geologic Atlas*, No. 151, text and structure sections.

There are more oil horizons in the stratigraphic section of this province than in any other province in the world. Fifty-six distinct horizons have been found to contain oil or gas or both. A few of these are limited to New York, but the others are found to be productive in the states farther south. By far the greater number are true sandstones with an average porosity of approximately 16 per cent. Most of them are fine-grained and they vary in thickness within wide limits. The thickest is the Big Injun sand which reaches a thickness of 400 feet in places. Four limestones are included in the list of productive horizons: the Greenbrier, Corniferous, Niagara, and Trenton limestones. They are uniform in thickness and may be traced throughout the province. This is not true of the sandstones, of course, although two of them do extend across the geosyncline. They are the Big Injun and the Berea. The Clinton sand of Silurian age may also be found to be equally extensive when further deep drilling has been done.

There are ten distinct horizons in the Pennsylvanian system, seven in the Mississippian, thirty-three in the Devonian, three in the Silurian, two in the Ordovician, and one in the Cambrian system. The Devonian horizons are most important both as regards number and total production. They are divided as follows: eleven in the Catskill formation, fourteen in the Chemung, six in the Portage, and two older horizons, the Corniferous and the Oriskany. In general, the producing sands in the northern part of the province belong to older stratigraphic zones, and the sands farther south belong to younger zones. In other words, Pennsylvanian and Mississippian sands produce near the southern and in the central part of the province, whereas the Devonian sands are productive in western Pennsylvania and New York. The oldest horizons are productive on the northern and western borders of the basin.

Although the anticlinal theory of oil occurrence was first conceived and demonstrated in the Appalachian geosyncline province because of the relation of gas, oil, and water in their proper position in the Volcano anticline, the relation is not so obvious in other parts of the province. Numerous maps have been prepared and published on the fields in Pennsylvania, West Virginia, and Ohio by the United States Geological Survey, state geological surveys, and others. Study of these maps emphasizes the fact that it is difficult to detect any relation between production and structure. Evidently other conditions than the attitude of the strata must be brought forward to explain the localization of oil and gas. Difference in the water saturation of the sand has been suggested as one reason for this lack of correspondence with structure. Differential

porosity has undoubtedly been an important modifying condition. The lenticularity of the sands is also well demonstrated and this factor helps to explain some peculiarities of occurrence.

CINCINNATI ARCH PROVINCE

The second group of oil and gas fields, according to the tectonic classification, is the group which is associated with the Cincinnati arch. This arch extends from northern Alabama in a direction nearly north to northern Ohio and into Ontario, Canada. It was formed in one of the periodic *shrinking* periods of the earth's crust, which has been called the Taconic revolution. During the Georgic, Acadic, and Ozarkic periods (Cambrian time) and the Canadic, Ordovicic, and Cincinnatic periods (Ordovician time) a nearly unbroken expanse of sea water had covered the continent west of the land masses of Appalachia and Laurentia, in which mostly limestones and dolomites had accumulated. In the Lowville stage of the Ordovicic period the first permanent island appeared in this sea, forming the nucleus of the Cincinnati arch. This part is located in central Tennessee and has been called the Nashville dome. During the succeeding Trenton stage another permanent island was formed in the central part of Kentucky, which has been called the Jessamine dome. The other parts of the arch also developed at this time because of differential subsidence, but did not remain permanently above water. From Cincinnati north through western Ohio to the Lima region, where the axis bifurcates, one arm trending northwest through Indiana and the other northeast into Canada, emergence was not prolonged much beyond the beginning of the Cincinnatian period. However, it was long enough to permit extensive solution cavities to form in the exposed Trenton limestone to furnish an excellent oil reservoir.

On this arch there are three districts which must be considered separately because they reveal rather decided differences in the age of the producing horizon, the relation of production to structure, and the kind of oil reservoir. The northernmost district has long been known as the Lima-Indiana district and there appears no good reason for changing this name. It includes fields in western Ohio and eastern Indiana. The oil in this district occurs almost exclusively in limestone of Middle Ordovician age, the Trenton limestone. Differential porosity induced by solution seems to explain the localization of the oil in the district, although the influence of the doming of the strata on the axis of the arch has also undoubtedly been of great importance. Small amounts of oil have been found in the Silurian limestones, the Cincinnati shales above the Tren-

ton, and in the St. Peter horizon (magnesian limestone) below the Trenton.

The second district in the province has been named by the writer after a county in south-central Kentucky, the Cumberland saddle district. The rather pronounced saddle between the Nashville dome and the Jessamine dome has an axis trending nearly east and west through Cumberland County. Inasmuch as this saddle seems to have exercised a controlling influence over the localization of the oil, it seems appropriate to apply the name of the saddle to the district. In the eastern part of the saddle lie the fields of Wayne and McCreary counties, and in the western part of the saddle are the fields of Allen, Barren, and Warren counties. The two groups of fields are on opposite sides of the Cincinnati arch, but are genetically related to it and especially to the saddle which crosses it.

In Wayne and McCreary counties the oil horizon is called the Beaver Creek sand. It is a cherty limestone with many geodes and belongs to the Waverly series or formation of Mississippian age. The relation between production and structure is not at all close and oil accumulation has probably been governed entirely by differential porosity. In Allen, Warren, and Barren counties oil has been found in eight or nine different horizons, six of which have commercial importance. They are: St. Louis limestone and Beaver sand in the Mississippian system, the Corniferous of the Devonian system, and the Niagara limestone of the Silurian system. In some of these oil is found at several levels within the same formation, but the Niagara limestone is the most important of all the producing formations. As regards the relation of structure to production we find considerable variety in this part of the Cumberland saddle district. St. Clair reports that most of the wells in the Niagara are located on the tops or high on the flanks of anticlines or domes. The oil in the Beaver sand seems to be controlled entirely by porosity conditions, and structure is subordinate; while the oil in the basal part of the St. Louis limestone is quite independent of structure.

The third district in this province was named the Alabama-Mississippi district because production has been found in both of these states, but not enough drilling has been done to demonstrate what structural feature the pools may be related to. They seem to lie on the projected continuation of the axis of the Cincinnati arch. Small gas pools have been found in this district: one in northwestern Alabama and another in the northeastern part of Mississippi. In both pools the gas was found within rocks of Pennsylvanian age (Pottsville).

EASTERN INTERIOR COAL BASIN PROVINCE

The Eastern Interior coal basin lies chiefly in parts of Indiana, Illinois, and Kentucky. An imaginary line circumscribing the basin extends from northwestern Indiana southeastward to the southeastern corner of the state, and enters Kentucky in the west-central part. It swings abruptly southwest and west and finally northwest, entering Illinois close to the junction of Ohio and Mississippi rivers. Thence it trends north parallel with Mississippi River to Rock Island County, turns sharply east and ends at the starting point in Indiana.

The oil pools and fields are located in southern and southeastern Illinois, southwestern Indiana, and northwestern Kentucky. The tectonic elements which have exerted an influence on the migration and accumulation of oil in these pools are the Cincinnati anticline, the La Salle anticline, and the Rough Creek fault zone. The first of these forms the eastern and northeastern rim of the basin, the second trends northwest and south-southeast in the eastern part of Illinois, and the third trends nearly east and west through western Kentucky. The La Salle anticline and the Rough Creek fault zone seem to have been the immediate cause for oil accumulation, and the influence of the Cincinnati arch is very subordinate.

The producing horizons in this province belong to the Pennsylvanian, Mississippian, Silurian, and Ordovician systems. The most important horizons occur in the Mississippian system; the less important, in the Pennsylvanian. In the Kentucky part of the province there are six important producing horizons, all in the Mississippian system and all sandstones with one exception (the Warsaw limestone). In Indiana eleven distinct horizons have been identified, one of which is basal Pennsylvanian, eight are Mississippian, and one is Devonian (Corniferous). In Illinois there is a still greater variety, for twenty-two horizons have been described. Some of these may be found to be the same, however, as the sands are strikingly lenticular and correlation throughout extensive areas is impossible. Eight of the horizons are of Pottsville age, nine of Chester (Mississippian) age, one of St. Genevieve, one of Kinderhook age. With few exceptions these are limited to the main producing fields in southeastern Illinois. The lower sands, two of which lie in the Silurian and one (Trenton) in the Ordovician, produce in the pools of western Illinois.

As regards the relation between structure and production it is obvious that the major tectonic elements previously mentioned have been

of importance in localizing the fields as a group. For example, the steeply plunging nose at the south end of the La Salle anticline has the most prolific fields related to it. Subordinately also there seems to be a significant relation between domes, noses, and small anticlines which are situated on the larger features. The scattered pools in western Illinois seem to coincide remarkably well with favorable structural conditions such as domes and anticlines.

MICHIGAN BASIN PROVINCE

The Michigan basin is a somewhat smaller basin than the Eastern Interior coal basin. The center of the basin lies nearly in the center of the southern peninsula of Michigan. The border of the basin on the south is formed by the two prongs of the Cincinnati arch. It will be recalled that this arch divides in southwestern Ohio, one prong trending northwesterly toward the southern end of Lake Michigan, the other prong trending nearly north through western Ohio to the western end of Lake Erie, where it takes a northeasterly course. The basin is bordered on the east, north, and west by outcrop bands of Ordovician and Silurian rocks which make almost a complete circle. The two lakes, Michigan and Huron, lie within this larger circle and are located where the relatively less resistant Upper Silurian sediments were removed by erosion. Still farther within the basin and dipping inward from all points are narrow concentric bands of Devonian and Mississippian rocks, and the central part is filled with strata of Pennsylvanian age.

Two oil fields of importance have been found in the Michigan basin and several other promising areas have been proved to contain oil on the showing of a few wells. The two fields which are now producing oil in commercial quantities are the Saginaw pool in the eastern part of the basin and the Muskegon field, almost opposite it, on the western side of the basin.

At least four producing horizons have been found. One of these is the Berea in the Mississippian system, two are in the Traverse formation of Devonian age, and the fourth is the top of the Dundee limestone which is also of Devonian age. The last mentioned is the producing horizon in the old Port Huron field as well as in the new Muskegon field. The Traverse produces in the Saginaw as well as the Muskegon pools, and the Berea is the chief producer in the Saginaw pool.

WESTERN INTERIOR COAL BASIN PROVINCE

The Western Interior coal basin covers a large area in the central part of the United States. It includes southwestern Iowa, northern

and western Missouri, southeastern Kansas, eastern Oklahoma, and northwestern Arkansas. It is on the eastern border of a much larger basin which has been called the Rocky Mountain geosyncline basin and is therefore not exactly comparable with the Eastern Interior coal basin or the Appalachian geosyncline. In these two the whole basin is filled with coal-bearing rocks of Pennsylvanian age or older rocks, whereas in the western basin younger rocks also appear at the surface. In the Rocky Mountain geosyncline basin rocks of Mesozoic and Cenozoic age cover nine-tenths of the present surface. Bearing in mind, therefore, that the Western Interior coal basin is but a part of a larger structural basin, we may use it in our classification.

This province includes the oil fields of eastern Kansas and northern Oklahoma. The most northerly field in the province is the Craig gas pool in Johnson County, Kansas, and the most southerly is the Ada gas pool in Pontotoc County, Oklahoma. The length of this oil-bearing zone is 250 miles. The most easterly field is the Poteau gas field of eastern Le Flore County, Oklahoma, and the most westerly is the Fairport field with its related pools in Kansas. The width of the oil-bearing zone at present is approximately 240 miles, at its widest part.

The tectonic elements which have been factors in the oil accumulation of this province are the Ozark dome, Ozark arch, Nemaha Mountains, Barton arch, Salina basin, and eastern Kansas basin. The Ouachita-Arbuckle-Wichita-Amarillo mountain chain has also had some influence on the history of the province and is here considered as the southern boundary of the province.

A clear understanding of the origin and growth of these tectonic features would contribute to a better understanding of the origin, migration, and accumulation problems in this province. We do not have complete data regarding their origin and development at present, but we do have enough to give a fairly satisfactory history of the tectonic features. In early Paleozoic time the epeiric sea stretched from the Appalachian geosyncline to the Cordilleran geosyncline with small interruptions. The area of most rapid subsidence was a narrow zone parallel with the land mass of Appalachia and Llanoria, and it is possible that a geosynclinal trough extended from New England through the Appalachian states into Alabama, thence westward through Mississippi and southern Arkansas into southern Oklahoma. North and west of this trough deposition went on with periods of interruption, and subsidence was slower. In fact, certain loci soon developed where subsidence stopped altogether. One of these loci was near the site of Nashville,

Tennessee, and another was in southern Missouri. The former was the nucleus of the Cincinnati arch and the latter of the Ozark dome and its extensions. These nuclei began to function as positive elements in Middle Ordovician times. Meanwhile two of the many granitic islands which had existed in the epeiric sea began to subside and were covered in part by Ordovician strata. One of these is the north-south trending granite ridge which has been called the Nemaha Mountains, and the other is the east-west trending granite ridge in southern Oklahoma and the Panhandle of Texas. They also were positive elements during the Silurian and Devonian periods while the small basins such as the Arkansas Valley trough, the eastern Kansas basin, and the Salina basin were subsiding and receiving sediment.

During the Mississippian period subsidence again became more general so that large parts of the granite ridges as well as the Ozark arch and the Barton arch subsided in unison with the basins. After a period of erosion the same thing happened during the Pennsylvanian period, but this time an even larger part of the positive elements was affected. A fact that must constantly be kept in mind is that *subsidence* is *differential*. Some parts of a basin subside more rapidly than others and the same is no doubt true of the positive elements which occasionally become submerged for a short time. Proof of this is found in the great differences in the thickness of contemporaneous sediments. No better diagrammatic demonstration of this can be found than in the excellent work of Levorsen.[1] For example, in a line nearly parallel with the axis of the Arkansas Valley trough in eastern Oklahoma, he shows that the thickness between the middle Pennsylvanian and the Ordovician strata changes from 2,000 feet to nearly 22,000 feet, or at the rate of 250 feet per mile.

If we appreciate fully the significance of this differential subsidence we can also see the reason for the formation of the Prairie Plains monocline, which is the characteristic structure of the surface rocks in the Western Interior basin at present. For, after the Pennsylvanian period had ended, subsidence practically ceased in the Western Interior coal basin province, but became very much accentuated in the adjacent part of the Rocky Mountain basin just west of it. Some of this subsidence occurred probably in the early part of the Mesozoic era, but most of it clearly happened during the Cretaceous period. The *subsurface effect* of this greater subsidence in the area west of the province is even

[1] A. I. Levorsen, "Convergence Studies in the Mid-Continent Region," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 11, No. 7 (July, 1927), p. 657 *et seq.*

more startling and interesting. For by this simple expedient we have the Bend arch formed in Texas, the Ozark arch in Oklahoma, and numerous smaller anticlines and domes in the buried strata.

In this province the horizons which produce oil and gas occur in all parts of the stratigraphic section from the lowest Ordovician formation to the highest Pennsylvanian formation and even in the Permian. The most important producing horizons are the "Siliceous lime" (Arbuckle limestone) and "Wilcox" sand in the Ordovician system; and the Dutcher, Bartlesville, and Calvin series of sands in the Pennsylvanian system. In Kansas twenty-nine distinct stratigraphic levels have furnished oil or gas horizons. Of this number possibly eleven are of considerable importance. In Oklahoma at least thirty-six horizons are productive, of which approximately twenty may be regarded as of great commercial importance. Most horizons in both states are in the Pennsylvanian system, and the Cherokee formation within the system has furnished the greatest percentage of important producing formations.

An impartial analysis of the peculiarities of oil occurrence in the whole producing territory in this province indicates that structure has had a profound influence on the migration and accumulation of oil in *a large way*, but that *locally other conditions* have been so potent as to make the relation obscure. The controlling structural element in the province is of course the Prairie Plains monocline. The prevailing dip of the surface rocks and of most of the subsurface rocks toward the west, at different rates, has influenced the migration of oil toward the east. On its long (or more probably short) journey it was intercepted by high and large anticlines or domes in the western part of the province, but in the eastern part of the province by much smaller and lower folds. In fact, in the easternmost part of the area, pinching sands and differential porosity seem to outweigh the importance of structure entirely. Some exceptions to these broad generalizations must be made, of course. For example, it seems to be well established that the production from the "Wilcox" horizon, which is now so great as to constitute more than half of Oklahoma's total production, occurs under definite folds which resemble small domes on the producing horizon, but are reflected on the surface by small noses or plunging anticlines.

OUACHITA-AMARILLO MOUNTAIN PROVINCE

In southern Oklahoma, north-central Texas, and the Panhandle of Texas there are fields and pools which are clearly related to a tectonic element that has been called the Ouachita-Arbuckle-Wichita-Amarillo

mountain trend; therefore, the province in which the fields are located may be called the Ouachita-Amarillo mountain province. The oil and gas fields which are included in this province extend from east-central Marshall County, Oklahoma, through Beckham County, into the Panhandle of Texas as far as Oldham County. The oil fields in Clay, Wilbarger and Wichita counties, Texas, which lie south of Red River, also seem to belong in this province.

The major tectonic elements in this province are seven in number. They are the Ouachita Mountains, Arbuckle Mountains, Wichita Mountains, and Amarillo Mountains, all of which are positive elements, and the less well-known element which has been called the Red River uplift. In addition there are two negative elements of importance: the Anadarko basin and the Red River syncline. No detailed description of these is necessary because all, with the possible exception of the Red River uplift, have been well described in the literature. Hager described the Red River uplift[1] on the basis of some deep wells which had encountered the Ordovician strata in Clay and Wichita counties, and some of which had entered granite. The presence of this tectonic element is now well established, according to the work of Fuqua and Thompson.[2]

The producing horizons of the Ouachita-Amarillo province belong to the Permian, Pennsylvanian, and Ordovician systems. In the Arbuckle-Wichita district oil has been found at many stratigraphic levels in the thick Pennsylvanian and Permian systems, but they are extremely patchy and local in their development so that it is impossible to correlate them from one pool to another. As many as eleven sands have been found productive in one pool (Empire pool, Stephens County), but this is exceptional. The Glenn formation produces the most oil in the district and the Pontotoc formation is second in importance. The Ordovician horizons, Viola, "Wilcox," and Arbuckle, are productive in three pools only (Robberson, Healdton, and Crinerville), although they have been reached and tested in several other pools. They of course occur throughout a wide area and may be correlated.

In the Red River district of north-central Texas similar conditions exist, with the exception that no production has been found in Ordovician rocks. Many stratigraphic horizons in the Permian and the Pennsylvanian systems (Wichita, Cisco, and Canyon formations) produce oil,

[1]Lee Hager, "Red River Uplift Has Another Angle," *Oil and Gas Journal* (Oct. 17, 1919).

[2]H. B. Fuqua and B. E. Thompson, "Relation of Production to Structure in Central Wilbarger County, Texas," *Structure of Typical American Oil Fields, A Symposium*, Vol. 1; *Amer. Assoc. Petrol. Geol.* (1929), pp. 293-303.

but they also are characterized by extreme lenticularity and patchy distribution. In the Electra and the Petrolia fields it is thought that the deepest sands are in the Mississippian system. In the Amarillo Mountain district oil and gas have been found in the porous zones of the so-called "Big lime," which is probably of Permian age. Oil also occurs in the talus slopes of the old mountain mass in material called "granite wash."

In regard to the relation between production and structure, there are some differences in the three districts of the province. In the Arbuckle-Wichita district there is a very close relation between structure and production. In practically every pool where the structure has been mapped and the data published it is found that the oil and gas occur on anticlines or domes. Most of these show strongly-arched strata in the Ordovician system and less strongly-arched strata in the overlying Pennsylvanian system, although the Permian rocks as a rule are but slightly disturbed. The fact that two zones of Ordovician disturbance cross each other in this province, the north-south Bend arch-Ozark arch axis and the east-west Ouachita-Amarillo axis, possibly explains the larger number of pools and the greater oil production in Stephens County, Oklahoma, and in Clay County in north Texas, for migration toward this crossing of zones has been from the east and west as well as from the north and south.

Our information on the structural conditions in the oil pools of the Red River district is sketchy and incomplete. Udden and Phillips report that the Petrolia field is anticlinal, that Burkburnett is on a broad anticline, and that the Electra field is on a broad anticline with a flat crest. Structure is not easy to map because of the lack of favorable key beds. It is not improbable that future drilling in these fields will show that the Pennsylvanian strata are arched more than the Permian strata.[1]

In the Amarillo Mountain district the relation between production and structure is very close. A large and long anticline lies over the buried granite mountain and there are domes on the broad anticline. Oil, gas, and water have accumulated and separated in this anticline according to the well-known theory of I. C. White. The cause of the arching of the Permian and Pennsylvanian strata over the granite ridge is probably differential subsidence. The subsidence toward the north and toward the south probably occurred along old shear zones as suggested by faults in the Permian strata (described by Bauer[2]).

[1]See also article by Fuqua and Thompson referred to on preceding page.

[2]C. Max Bauer, *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10 (1926), p. 741.

BEND ARCH PROVINCE

South of the Ouachita-Amarillo province and separated from the fields therein by a fairly deep syncline or saddle are the fields of north-central Texas. They are in Comanche, Brown, Coleman, Erath, Eastland, Callahan, Palo Pinto, Stephens, Shackleford, Young, and Archer counties. The controlling tectonic element in this province is the Bend arch. This arch is not shown in the surface strata, but is indicated in the structural attitude of the members of the lowest Pennsylvanian strata, which are called the Bend series or formation;[1] hence, the arch is called the Bend arch. It is a broad, relatively flat arch with a fairly uniform pitch toward the north from the Llano uplift in central Texas. It is modified by terraces and cross folds at several places, for example, the Gorman anticline. The rocks above the Bend series show very slight departures from the normal westward dip of the region.

The most important producing horizon in this province is the Marble Falls limestone of the Bend series. It contains two porous zones: one at the top and another approximately 200 feet lower (Ranger sand). In the northern part of the province considerable oil is also derived from local sands, lenses in the Strawn formation, as many as six sands having been found in one pool (South Bend pool). The Smithwick shale produces oil from porous limestone streaks.

The relation between production and structure is not so definite in this province as in some of the other provinces. In a broad general way we must admit that accumulation has taken place according to the anticlinal theory, because the localization of the oil on the crest of the Bend arch can not be explained in any other way. The distribution of the oil in pools on the crest does not seem to depend on structure. The surface folds which depart from the regional monocline are almost without exception small noses which pitch northeast and northwest on the two sides of the arch. Oil has been found beneath some of these, and below many of them the subsurface structure is very much accentuated; however, as oil has also been found under surface structures of every other kind, we must conclude that the local accumulation has occurred according to differential porosity in the limestone and according to differences in the thickness and the porosity of the sandstones. The McClesky sand in the Ranger pool, which is the lower porous zone in the Marble Falls limestone, strikingly illustrates this. This sand has a thickness ranging from 30 to 50 feet where the production is greatest and no production is found where it is less than 25 feet thick.

[1]The Bend series is considered of Mississippian age by J. Perrin Smith based on a study of ammonoids collected by Charles L. Baker.

GULF EMBAYMENT PROVINCE

This province includes parts of the states of Texas, Louisiana, and Arkansas. Because of structural conditions subordinate to the main tectonic elements, four districts may be differentiated. In eastern Texas a long narrow line of pools constitutes the Balcones fault district. Farther south (and possibly an extension of the first district) lies a similar line of pools in the Reynosa escarpment district. In northern Louisiana and southern Arkansas are several fields and pools which have a genetic relationship. As they are related to the Sabine and Ouachita uplifts, they are included in the Sabine-Ouachita uplifts district. Finally, in southeastern Texas and southern Louisiana are many pools which are quite different from the others mentioned and all related to salt domes. These constitute the fourth district, the Salt dome district.

The controlling tectonic elements in this province are the Balcones fault zone, Mexia fault zone, Steen-Palestine fault zone, Luling fault zone, Webb-Zapata counties fault zone, many unnamed fault zones in the coastal Salt dome area, Sabine dome, and the Ouachita dome. The imposing array of fault zones gives the impression that the province is characterized by lines of faulting instead of lines of folding. This is entirely correct, for every district is fundamentally affected by faults even though they may not be present at the surface or in the surficial rocks.

These faults and fault zones constitute a symmetrical series which together make a huge arc convex toward the west, northwest, and north, indicating that they have a common origin. Briefly described, they are the result of the foundering of a large land mass which existed in the Gulf embayment during Paleozoic and early Mesozoic times. This ancient land mass has been called Llano or Llanoria (Llanoris). The sinking of this segment of the earth's crust caused tension faults to form on the periphery and along certain lines of weakness. Some of the times of profound movement along these lines may be determined by the geologic record in the Ouachita Mountains and the Llano-Burnet uplift. In both of these areas the latest faults are pre-Cretaceous and post-early Pennsylvanian. Farther within the embayment faulting occurred during Cretaceous time, after Cretaceous time, and during Tertiary time.

The Sabine dome in northwestern Louisiana has a diameter of approximately 80 miles measured on the Pecan Gap-Annona chalk horizon with rather steep dips on the southeast, south, and southwest. This dome is probably caused by vertical movement along an ancient fault plane in the pre-Cretaceous rocks. Renewed faulting during Cretaceous

time is indicated by the steep dips in the Trinity strata and the fact that Fredericksburg strata are missing entirely and the Washita strata are present only on the southern flank. Disconformities between the Midway and the Wilcox and between the Wilcox and the Claiborne suggest renewed movements during Tertiary time. Faults have been discovered by drilling at Homer, Bull Bayou, Haynesville, and other places. Volcanic ash interbedded with the sediments also suggests diastrophic movements, as do the interior salt domes.

The Ouachita dome is located in Richland, Ouachita, and Morehouse parishes, Louisiana, and extends northwest into Union, Calhoun, and Ouachita counties, Arkansas. It probably owes its structure to deep-seated faults, evidence of which has been found along the southwest side of the dome. A fault in the basement complex producing an escarpment facing the southwest would readily account for the elongate dome in the surface rocks.

The producing horizons in the province differ somewhat in the four districts, but are confined to the Tertiary and Cretaceous systems. In the Balcones fault district seven distinct horizons of importance have been found, of which the Edwards and Woodbine are the most important. The others lie higher in the Cretaceous system, a peculiar one being the altered igneous rock which produces oil at Thrall and Lytton Springs. In the Sabine-Ouachita district oil or gas has been found at ten different stratigraphic levels. The youngest is the Wilcox, which produces at Urania, and the oldest is the Glen Rose, which produces at Cotton Valley and Pine Island. The Nacatoch sand has been the most consistent and the largest producer of oil and gas in the district. In the Reynosa escarpment district oil and gas have been found at three different horizons at least. Sands in the Yegua and in the Fayette furnished most of the production until recently when the Cook Mountain was found to contain oil in certain pools. In the salt dome province production is obtained from many different stratigraphic levels. Sands are very patchy and lenticular so that none can be traced from one pool to another. They occur above the cap rock of the dome or on the flanks of the dome. The cap rock also is a producing horizon in many domes. Up to date most of the oil has been obtained from horizons of Miocene and Oligocene age.

A comparison of the effect of structure on production reveals an interesting variety of conditions. In the Balcones fault district and the Reynosa escarpment district faulting is accountable for the trapping of oil and gas in commercial quantities. In some pools the influence of

faulting is not immediately apparent; for example, in the old Corsicana and Powell pools. Again in the peculiar pools where "serpentine" is the oil reservoir the effect of faulting may be subordinate to the condition of porosity in the altered igneous rock.

In the Sabine-Ouachita district the relation between structure and production is strikingly close. Not only have the major tectonic elements controlled migration and accumulation, but many of the minor structural elements have served to trap the oil and gas. Among the minor structures are small anticlines as well as large anticlines with subordinate domes and anticlines on them. There are also faults and faulted anticlines. The relief of some of the small anticlines is remarkable (Bellevue and Homer), although some of the pools are on anticlines with rather low relief.

In the salt dome district the relation between structure and production is also strikingly in accord with the anticlinal theory. Where the strata are arched above the salt plug, oil and gas have assumed as high a position as the porosity of the sands would allow. Where the salt plug has penetrated the sands, the fluids are ponded against the vertical barrier or else have taken a peripheral position because the sands pinch out against the salt mass.

WEST TEXAS BASIN PROVINCE

This is the most recently discovered oil province, its history dating from 1921. The largest and controlling tectonic element in it is a syncline trending nearly north and south from Pecos River in southern Crane County, Texas, to Hockley County and beyond. On the east the basin is bounded by the Bend arch, on the southeast by the probable continuation of the Marathon arch, on the south by the Glass Mountains, the Delaware Mountains, and the Guadalupe Mountains. On the west and northwest its boundaries are not defined, but lie somewhere in central New Mexico. On the north it is bounded by the Amarillo Mountains. Minor structural features which modify the attitude of the rocks in the basin have been discovered in drilling. The plunging anticline through Foard, Cottle, Motley, Floyd, and Hale counties is an example. This anticline as well as other similar folds may reflect buried hills or deformation at depth.

The most important producing horizons in this province are contained in the so-called "Big lime," a dolomitic limestone of Permian age. Porous zones occur at many levels within the limestone. In the Chalk pool, for example, three porous zones have been found within a thickness

of 1,800 feet. The porous zones range from 10 to 60 feet in thickness and occur uniformly with certain vertical limits within the same pool. As a rule the best production is obtained from porous zones lying within 500 feet of the top of the "Big lime." In one pool at least an oölitic limestone is the producing horizon. Locally Permian sandstones above the "Big lime" have produced oil and gas, for example, two upper zones in the Chalk pool, and the Yates sand.

Domes and anticlines with considerable relief account for the localization of the oil and gas in this province. In the Big Lake pool, for example, the dome has a closure of at least 125 feet, and in the Church and Fields-McElroy field the closure amounts to more than 300 feet on the producing horizon. On the periphery of the basin the relief of the domes and anticlines is not so great (Artesia, New Mexico, and Westbrook pool, Texas).

ROCKY MOUNTAIN BASIN PROVINCE

The largest, or the most extensive, group of oil and gas fields according to the tectonic classification is related to the Rocky Mountain basin, or geosyncline. This basin is a part of the Cordilleran geosyncline, which includes the states of Montana, Wyoming, Colorado, eastern Utah, and northern New Mexico. The Cordilleran geosyncline, with its extensions, covered a vast area reaching from the land masses of Laurentia, Ozarkia, and Llanoria on the east to Cascadia on the west. It was in existence during Proterozoic time and continued to be the site of deposition during Cambrian time. In the rocks of the Ordovician period we see the first signs of the disturbances which culminated (after many repeated times of disturbance) in the Jurassic period by the formation of the Cordilleran intermontane geanticline. Thereafter two basins existed within the confines of the original geosyncline, one of which has been called the Pacific geosyncline and the other the Rocky Mountain geosyncline. Sedimentation was extremely rapid in this basin during Cretaceous time, as indicated by the enormous thickness of shales and sandstones of that age now found there.

The western side of the province is characterized by overthrust faults beginning with Chief Mountain overthrust in Montana. Southward the Phillipsburg and Lombard faults lead to the Heart Mountain thrust in northwestern Wyoming which in turn gives way to a zone of faults in southwestern Wyoming: the Bannock, Absaroka, and Darby faults. Here an east-to-west thrust fault is interposed in the Uinta Mountains. East of this belt of faults there are many tectonic elements which have had an influence on the accumulation of oil in the province.

Beginning at the north, we find two positive elements in Montana on which the oil fields of that state are located. One has been called the Sweetgrass arch and the other the Big Snowy anticlinorium. In Wyoming the negative elements are more important. Five structural and topographic basins in that state contain all the oil pools of the state. They are the Big Horn, Green River, Wind River, Laramie, and Powder River basins. With a few exceptions the oil pools are grouped on the peripheries of these subordinate basins. In Colorado there are two similar basins and part of another. The Uinta basin is in the northwestern part of the state reaching over into Utah. In front of the Rocky Mountains in eastern Colorado lies the Julesburg basin and in the southwestern part of the state lies a part of the San Juan basin. In northwestern New Mexico the oil pools in the main part of the San Juan basin belong to the Rocky Mountain province.

Oil and gas have been found in eleven formations of the stratigraphic section in this province. Of these the Madison limestone of Mississippian age is the oldest (Kevin-Sunburst) and the Steele formation of upper Cretaceous age is the youngest. In Montana six formations have been found productive; in Wyoming, nine; in Colorado, four; in New Mexico and Utah, one. The formation which is present throughout the province and which is very prolific at many places is the Dakota sandstone, found at the base of the Cretaceous system. In Wyoming productive sands have been found at eighteen different horizons, of which the most important lie in the Frontier formation (Wall Creek sands). This formation produces oil in each of the five districts in the state. In the Big Horn basin district the Dakota and Embar (Mississippian) horizons are also important. In the Wind River basin district the largest amount of oil has come from the Park City member of the Embar formation. The Sundance sands are next in importance, especially on the east side of the district. The Frontier sands are chiefly gas sands in this district. In the Green River basin district the Dakota sandstone has furnished the most important production, but sands in the Hilliard, Mowry, Cloverly, and Sundance are also productive. In the Laramie basin district the Dakota also is the important horizon, and the sands in the overlying Mowry shales called the First and Second Muddy sands are locally important producers. The Powder River basin district contains the most prolific fields in the state as well as the greatest number of producing horizons. The Shannon, First, Second, and Third Wall Creek sands, Mowry sands, Dakota, Lakota, Sundance, and Tensleep horizons all furnish oil or gas or both.

In Montana three horizons produce large quantities of oil: the Cat Creek (Dakota), Sunburst (Kootenai), and Campbell (Madison lime) horizons. In addition, subordinate amounts of oil and gas are found in four other horizons extending from the top of the Cretacous system to the top of the Mississippian system. In Colorado three shale horizons and one sandstone have been found productive. The latter is the Dakota, which produces large amounts of oil as well as gas. The shale horizons are in the Pierre (Florence), the Mesaverde (DeBeque) and the Mancos (Uinta basin district). The "Muddy" sand of the Dakota formation produces in the Green River basin district, the Uinta basin district (gas), and the Julesburg basin district (eastern Colorado). In New Mexico there is only one district which belongs to this province. It is the San Juan basin district in the northwestern part of the state. The producing horizon here is the Dakota sandstone. It produces oil in the Hogback, Rattlesnake, and Table Mesa domes and large amounts of gas in the Ute dome. In the Aztec dome the gas seems to occur in the Farmington sand, a sandstone in the Kirkland formation.

In Utah the Ashley and Cisco domes, on which gas has been discovered, are in the Uinta basin district, and produce from the Dakota horizon. In the San Juan River uplift district, production has been found in the Goodrich (Pennsylvanian) formation at ten different levels, but in very small amounts.

In the Rocky Mountain petroliferous province the relation of production to structure is strikingly close as a general rule. More than 95 per cent of all pools in the province are on domes or anticlines which have closures of hundreds of feet. Some structures have closures of more than 1,000 feet. Domes and anticlines have trapped the oil and gas in Montana, all of Wyoming except the eastern part of the Powder River basin district, most of Colorado, northwestern New Mexico, and eastern Utah. The Sweetgrass arch in north-central Montana differs from the typical structure chiefly in its great size and the peculiar localization of the oil pools on the northwest side. The exceptional pools in eastern Wyoming differ because they are accumulations on terraces instead of on domes or anticlines. The exceptions in eastern Colorado differ even more notably because there is no structural trap. The fissured nature of the shales seems to be the cause for the accumulation at Florence and in the old Boulder pool. In the typical oil trap of this province oil, gas, and water have arranged themselves according to the orthodox theory, but the desirable fluids are not ordinarily plentiful enough to fill the trap, so that only a small part of the closure area is productive.

However, there is a variation in this feature from pool to pool, and from horizon to horizon.

PACIFIC GEOSYNCLINE PROVINCE

The Pacific geosyncline was originally a part of the Cordilleran geosyncline. It began an independent history toward the close of the Mesozoic era after the formation of the Cordilleran geanticline. It consisted of a series of long narrow troughs occupying a narrow belt which extended from Alaska along the Pacific coast as far as southern California. In these troughs subsidence was rapid during Cretaceous and Tertiary times so that very great thicknesses of clastic materials accumulated. The oil fields in this province are in southern California and in southern Alaska.

Certain characteristics differentiate the fields of the Pacific geosyncline province from those of other provinces. The oil is found in Tertiary rocks, chiefly of Pliocene age, the producing sand zones are very thick (1,500 feet), the strata are strongly deformed, surface indications are exceptionally large and plentiful, and the oil is concentrated in small areas. Some of these characteristics are explained by the peculiar tectonic conditions and others by the nature of the Tertiary sediments.

The tectonics of the province have been described by Bailey Willis. He states that the predominant tectonic element or feature is the shear, as contrasted with the folds in most of the other provinces. In the Appalachian province, for example, long, well developed anticlines and synclines in parallel arrangement are characteristic even though thrust faults also exist. These thrusts are incidental and a result of rupture of overturned folds. In California, however, the folds are short, local, and are the subordinate features. The great batholiths which form the foundations of the Coast Ranges and the Sierra Nevadas, when subjected to horizontal pressure, found it easier to break than to bend. In doing so another fundamental difference was manifested. The faults produced by the shearing stand almost vertical at their outcrops instead of at a low angle as in the Appalachian province. The San Andreas rift is an example, and also indicates the principal trend of the faults. Similar and parallel faults have produced a mosaic in the basement rocks, producing blocks ranging from 10 to 30 miles in length and 4 to 15 miles in width. Actual movement of these blocks has been established in recent times by observations of the U. S. Coast and Geodetic Survey. Shearing began during Jurassic time and continued to the present.

The result of this in the oil fields has been twofold. Differential movements of blocks has produced different thicknesses of sediments and different sequences in adjacent areas. Another result has been the production of folds. These also are of two kinds. One kind is the anticline above a shear zone in the basement rocks which makes an angle with the trend of the fault according to the principle first enunciated by Fath (horizontal movement in the shear zone). The second kind is the fold produced in incompetent strata by vertical movement in the shear zone. Examples of both kinds of folds may be found in the oil fields of California.

In California the sands which produce oil are soft sands occurring as relatively thin layers within shales, but forming zones of very great thickness. Within a zone the sands are lenticular and differ in texture horizontally. Therefore correlation is impossible except by zones and even thus only within a single field. All Tertiary series, with the exception of the Eocene series, have furnished oil, but the Pliocene series leads when the number of pools is taken as a basis of comparison. It produces oil in 28 of the 47 pools listed by Gester.[1] Since his tabulation was made, further deep drilling in the Los Angeles basin district and in the San Joaquin valley district have opened new reserves in the Miocene which indicate that the Miocene may in time take first rank. When Gester made his tabulation 14 pools were producing from Miocene strata either wholly or in part.

Four districts may be differentiated in California on the basis of subordinate tectonic conditions. They are the San Joaquin valley, the Santa Maria district, Ventura district and Los Angeles basin district. In the first and fourth of these nearly all pools derive their oil from Pliocene strata, although the Miocene is becoming increasingly important. In the San Joaquin valley district two pools derive their oil entirely from Miocene strata. In the Santa Maria district more oil is produced from the Pliocene than from the Miocene. In the Ventura district the Pliocene produces oil in only two fields, but one of these, the Ventura Avenue pool, is by far the largest in the district. The other producing horizon of importance is the Oligocene, which, strangely enough, is not productive in any other district at present. No oil is found below the Oligocene with the possible exception of one small area in the east-side pool of the Coalinga field.

[1]G. C. Gester, "Observations Relating to the Origin and Accumulation of Oil in California," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10, No. 7 (July, 1926), pp. 697-702.

The relation between production and structure is very close in California in all four districts. The anticlinal trap is by far the most important structural trap as shown by Gester in the tabulation previously mentioned. Of 47 pools listed, 38 produce from an anticline or dome, 6 from a monocline or terrace, and 3 from an accumulation trapped by a fault. The last type of trap is also given as a minor cause of accumulation in 3 other pools. With the exception of the west side of the Coalinga field all pools in which accumulation has occurred on a monocline are small or insignificant. Similarly, the pools in which a fault has trapped the oil are unimportant with the exception of McKittrick, which probably should not be placed in this category.

CRITERIA FOR PETROLIFEROUS PROVINCES

In conclusion, we may recapitulate some of the outstanding features of the provinces described. Perhaps we may see in perspective what the criteria of petroliferous provinces are, or should be. If we examine the producing horizons, we notice that almost any porous horizon in the stratigraphic section may serve in that capacity. In other words, if the province contains strata of Ordovician, Silurian, Devonian, Mississippian, and Pennsylvanian age, as the first four do, we may expect to find oil in one or more horizons of each system. This is true in the first two, but only partly so in the third and fourth. In the fifth province, where the Permian system is well developed in addition to those named, it also contains producing horizons. The importance of the systems varies from province to province. In the first, it is the Devonian which carries the most oil; in the second, the Ordovician; in the third, the Mississippian; in the fourth, the Devonian. In the fifth, the Ordovician and Pennsylvanian share equally in importance. In the sixth province, where only the Ordovician, Pennsylvanian, and Permian are represented, all produce oil. In the seventh province, the Pennsylvanian is the only system which produces, and we find that it is practically the only system present besides the Ordovician. In the eighth province (Gulf embayment), the stratigraphic section begins with the Comanche rocks, but includes Tertiary strata. Therefore Comanche, Cretaceous, and Tertiary strata contain productive horizons. In the tenth province (Rocky Mountain), the stratigraphic section is the most inclusive, extending from the Ordovician through the Mesozoic periods into the Tertiary. We find production in Mississippian, Pennsylvanian, Permian, Triassic, Jurassic, Comanche, and Cretaceous strata, a remarkable showing. The only systems not represented are the Ordovician and Tertiary (the Silurian

and Devonian systems are missing in the section). Finally, in the eleventh province, only upper Mesozoic and Cenozoic strata are present in an unmetamorphosed condition. Both contain oil, though the Mesozoic is too insignificant to merit mention. Evidently the age of the producing horizons is not a criterion for a petroliferous province.

The lithology of the producing horizon differs more or less in different provinces. In some, sandstones predominate; in others, limestones assume greatest importance. In some districts sandstones and limestones are of equal importance. Rarely, other types of porous rocks are the producing horizons; for example, basalt agglomerate in the Conejo pool of California, or "serpentine" in certain pools of the Balcones fault district. The condition of porosity is the significant factor in each of these types and clearly can not be used as a criterion.

The relation of structure to production also is different in the several provinces. However, a careful inventory of all possible types of occurrence in all districts and all provinces brings out certain general features which will bear emphasis. First we notice that the large tectonic elements in each province, although subordinate to the major controlling elements, seem to have had direct control over migration and accumulation. For illustration, the Volcano anticline, with 900 feet of reverse dip, in the Appalachian geosyncline, and similar large anticlines in the province have caused large oil pools to form. In the Eastern Interior province, the La Salle anticline has caused the largest accumulations in the province. Similarly, the Granite Ridge of Kansas, the Sabine dome of Louisiana, the large buried hills of the West Texas basin, have caused oil pools to form.

However, when we examine the local and much smaller structures, situated on these larger structures, we notice some important differences. In some districts the oil has accumulated in these structures of the third order, whereas in others it has not. In some places one or the other of these generalizations is true of whole provinces.

If we classify the structural features according to rank, designating the largest, such as the Appalachian geosyncline basin and the Cincinnati anticline, as features of the first order, designating the La Salle anticline and the Granite Ridge of Kansas as features of the second order, and small domes, noses, and terraces as features of the third order, some interesting comparisons may be drawn. In the first three provinces structural features of the third order are ineffective in controlling accumulation, but features of the second order are quite effective. In the fourth province (Michigan basin) not enough drilling has been done

to determine the characteristics. In the Western Interior province, conditions differ in different parts of the province. For example, in the eastern part of Osage County, Oklahoma, structures of the third order seem to have furnished admirable traps for the oil and gas, whereas farther north (in eastern Kansas) accumulation seems to be quite independent of similar third-order structures. In the Ouachita-Amarillo mountain province, structures of the third order are fairly large domes and anticlines which show excellent relation to production. In the Bend arch province, such features as the large dome and terrace in southern Stephens and northern Eastland counties have evidently affected accumulation, but smaller features of the third order show very slight relation to production.

Conditions in the Gulf embayment province are somewhat peculiar so that exact comparisons can not be made. If we consider the individual faults of the different fault zones and the folds associated with each as features of the second order, we can report a close relation between production and second-order structures. In the Sabine and Ouachita domes district, the relation is close between both second- and third-order structures. The salt domes, in which production is closely related to structure, may likewise be considered features of the second order, although they are comparatively small.

In the Rocky Mountain province, structures of the second order are rather large. The Big Horn basin, Powder River basin, and Sweetgrass arch are examples. In these basins and on the arches are very symmetrical domes and anticlines, which in the former are distributed chiefly on the periphery of the basin. They are structures of the third order and show close relation between production and structure. In the Pacific geosyncline province, similar relation is found between the large domes and anticlines which are structures of the third order and are located within rather large basins as second-order structures.

CONCLUSION

We see from this comparative analysis that the age of the producing horizons is not a criterion for a petroliferous province. Nevertheless, the age of the rocks in a province depends on the time of existence of the tectonic element, either as a positive or a negative element; therefore, the producing horizons may be of similar age in basins of similar age. We also notice that the lithologic character of the producing horizons can not be used as a criterion. The type of second- and third-order structure may be used with certain limitations. Thus we may say that some

provinces have large structures of the second order and very symmetrical structures of the third order. We may call this the ***structural habit*** of the province. Most provinces, however, have complex structural habits, that is, they show various types of structure of second or third order, or both. The relation between production and structure depends upon the structural habit of the province as well as upon the nature of the reservoir; therefore, it can not be used as a criterion. No other single factor remains, therefore, except the structural features of the first order or the tectonic elements. These should be used in delimiting petroliferous provinces.

DISCUSSION

CHARLES LAURENCE BAKER:[1] Mr. Ver Wiebe's paper is an excellent compilation, evidencing much industry exerted to good purpose. It should be very useful. It might be well to add as a general axiom that the greater the amount of deformation the more perfect the anticlinal control of accumulation, with the exception that the law does not apply when the porous strata are not fully saturated. This statement is both elementary and simple, but is nevertheless important, inasmuch as it means that geology and geophysics are most useful in these particular structural conditions.

L. G. HUNTLEY:[2] The proposed system appears sound, from the standpoint of the oil geologists, as they have the main criteria in mind at all times and can make the necessary modifications and exceptions (additions) as may seem necessary.

As such a classification must necessarily be built up after the facts have been established by the drilling and development and geological work incidental to oil production, there must sometimes be a temporary geographical classification used, such as that now in use.

This original classification will be difficult to displace in the minds and usage of the non-geological fraternity and in the trade journals.

Another point of difficulty is apparent in displacing the present geographical classification of oil fields in the usage of the non-geological fraternity: between certain fields whose accumulation is controlled by position on high elements and those associated with geological basins there are found flanking regions and pools where classification is difficult. Examples may be cited such as certain districts in Kentucky between the Appalachian basin and the Interior Coal basin; and such as districts in north-central Texas between the Bend arch and the West Texas field. This may cause no confusion in the minds of geologists, who are familiar with all the criteria, but will not make for the necessary simplicity in the scheme of things for their non-technical associates.

There is another point of confusion allied to the last: identification of certain regions with great structural basins might cause the operator to ask em-

[1]Houston, Texas.

[2]Pittsburgh, Pennsylvania.

barrassing questions. The text-book geologists have talked indiscriminately of anticlines so long that such a seeming contradiction on the part of the geologist himself would be difficult to explain.

PRE-MISSISSIPPIAN SEDIMENTS IN CENTRAL KANSAS[1]

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ABSTRACT

The following pre-Mississippian beds have been found in Kansas: (1) a dolomite of possible lower Silurian age, (2) Maquoketa(?) shale, (3) Maysville-Eden(?) (upper Galena)(?) dolomitic limestone, (4) beds possibly Trenton in age, (5) lower Decorah beds of upper Black River age, consisting of siliceous dolomite, light brown finely-crystalline limestone, grayish-white coarsely crystalline limestone, pale grayish-green shale, deep olive-green shale, or sand, (6) a light brown sucrose dolomite doubtfully referred to the Platteville, (7) true "Wilcox" sand, (8) Simpson olive-green shale and sand, (9) "Hominy" sand, (10) Arbuckle limestone, (11) basal Paleozoic sand, and (12) pre-Cambrian schists and granite.

The following beds seem to be absent: the "Hunton" limestone and the Fernvale ("Viola") limestone.

There is an angular unconformity in Kansas immediately above the Arbuckle limestone, another beneath beds of lower Decorah (upper Black River) age, and another beneath beds of Kinderhook age. There may be other unconformities in the section. In any given area any one or several of the pre-Mississippian sediments may be present.

INTRODUCTION

The first published statement, so far as the writer knows, of the subsurface occurrence in western Kansas of Ordovician beds comparable with those which are exposed in Iowa, was by Jon A. Udden.[3] Under date of March 31, 1926, he states that shale samples between 3,340 and 3,380 feet in the Valerius Oil & Gas Company's test in the southwest corner of Sec. 3, T. 13 S., R. 13 W., had been identified as Ordovician in age by three capable paleontologists and had been correlated with the Decorah shale of Iowa by T. E. Savage of the University of Illinois.

W. H. Twenhofel[4] lists several wells in west-central Kansas from which he identified fossils of Decorah age that occurred in a green shale underlain by Ordovician limestone.

[1]Read by title before the Association at the Fort Worth meeting, March 21, 1929. Manuscript received by the editor, February 16, 1929.

[2]Shell Petroleum Corporation.

[3]Jon A. Udden, "Occurrence of Ordovician Sediments in Western Kansas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10, No. 6 (June, 1926), pp. 634-35.

[4]W. H. Twenhofel, "Ordovician Strata in Deep Wells in Western Central Kansas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 11, No. 1 (Jan., 1927), pp. 49-55.

Minute and fragmentary fossils have within the past year been found by the writer during the routine examination of the pre-Mississippian samples from drilling wells in Kansas. Much additional information could be obtained by the re-examination of samples from tests drilled in the past few years, since, no doubt, these fossils were overlooked in the first examination, and future wells will add to the fund of knowledge. The present paper is, therefore, merely a progress report, and gives such information as has, to date, been obtained by the writer.

The first part of the paper contains a list of the wells in Kansas, descriptions of the samples from which microfauna have been obtained, and the paleontologic correlations for these wells. The second part of the paper contains the results of petrologic studies of Kansas samples. The third part is a summary of the facts as known at present, together with some inferences from those facts.

ACKNOWLEDGMENTS

All fossils obtained from the Kansas samples herein described were submitted to Frederic A. Bush, of the Sinclair Oil & Gas Company, for identification. The writer wishes to express her deep appreciation to Mr. Bush for his sincere coöperation in the identification of these fossil forms, in the paleontologic correlations resulting therefrom, and in the preparation of the correlation chart. She is also deeply indebted to him for many valuable suggestions during the preparation of this paper, and for criticising the manuscript.

Grateful acknowledgment is made also to the Shell Petroleum Corporation for permission to publish the information herein contained.

PALEONTOLOGIC STUDIES OF KANSAS SAMPLES

Ramsey, Kaul No. 1, SW., NE., NE., Sec. 2, T. 11 S., R. 11 E.—This test encountered a most peculiar Mississippian limestone section, from 2,240 to 2,375 feet, which includes the St. Louis and possibly some of the Warsaw members. Below 2,282 feet the "Mississippi lime" consisted of alternating beds of cherty dolomite and limestone. The 6⅝-inch casing is set at 2,259 feet, near the top of the lime.

The top of the Kinderhook shale interval was a bed of soft, light pinkish-gray shale, from 2,375 to 2,390 feet. Light greenish-gray shale lay under the pink shale and carried the characteristic *Sporangites huronense* from 2,445 to 2,580 feet. Banded reddish-brown and greenish-gray shale carrying spores occurs from 2,580 to 2,585 feet, the base of the Kinderhook interval. The Kinderhook spores in the base of this

shale interval, 2,375 to 2,585 feet, are mentioned because some geologists have correlated this shale with the Maquoketa.

The test encountered cream-colored, "sugary" dolomitic limestone from 2,585 to 2,620 feet, passed through a 10-foot zone of white and gray semi-translucent chert, into cream to buff, finely crystalline, pure dolomite. The last sample received was from a depth of 2,650 feet and contained a small amount of irregular, subangular, frosted sand. Limestone, with a few sand layers, is logged to 2,830 feet, total depth. No fossils were found in the samples below the Kinderhook shale. The age of the dolomite in the bottom of this test is indeterminable at present.

Spencer, Taylor No. 1, center NE., SW., Sec. 5, T. 14 S., R. 8 E.—Well-log studies show that the "Mississippi lime" was probably absent in this test and that Kinderhook shale may have been present in the interval between 1,775 and 1,955 feet. The first sample received was from 1,983 feet, and from that depth to 2,090 feet the samples were of alternating beds of gray coarsely crystalline dolomite, white coarsely crystalline dolomite, gray finely crystalline limestone, and at the base, 2,081 to 2,090 feet, dirty gray dense and gray crystalline dolomite. The only chert in the whole interval was white opaque and gray semi-translucent, constituting approximately 30 per cent of the samples from 2,041 to 2,057 feet. The lowest sample contained a trace of gray and black oölitic chert. No fossils were found between 1,983 and 2,090 feet.

Grayish-green, soft, plastic shale occurs from 2,090 to 2,168 feet. No spores are present, but fragments suggesting annelid jaws were found in this shale, which may indicate its age as Richmond; therefore, the shale from 2,090 to 2,168 feet is correlated tentatively as Maquoketa shale.

From 2,168 to 2,242 feet the test penetrated a gray to cream-colored coarsely crystalline dolomite. No limestone and no chert were present, and no fossils were found in these dolomite samples, probably because of the intense dolomitization. No samples below 2,242 feet were received, but the test was abandoned in granite at 2,480 feet.

If the shale from 2,090 to 2,168 feet, below the first dolomite, is Maquoketa shale, as suggested by the fragments doubtfully identified as annelid jaws, then the dolomite above this shale is younger than Maquoketa. If the shale from approximately 1,775 to 1,955 feet is Kinderhook, as indicated by well logs, then the dolomite below this shale and above the "Maquoketa" is pre-Mississippian-post-Richmond in age, which would make it either Silurian or Devonian, probably lower Silurian in age.

Since the dolomite samples seen for 74 feet below the "Maquoketa" shale are non-fossiliferous, the age of the dolomite is indefinite, but 312 feet, only, of sediments (sand and lime, according to the log) intervene between the top of this dolomite and granite, reached at 2,480 feet.

Marland, Eagle No. 1, SE., NW., NE., Sec. 12, T. 14 S., R. 1 E.—This test had Kinderhook shale from 2,525 to 2,672 feet. Spores are present from 2,600 to 2,620 feet, and at the base, 2,660 to 2,672 feet.

An erosional zone, consisting almost entirely of weathered chert, which is a mass of sponge spicules, occurs below the Kinderhook shale from 2,672 to 2,690 feet. Eight-inch casing is set at 2,713 feet. The chert is underlain by 180 feet of cream-colored, finely crystalline sucrose dolomite, down to 2,870 feet. This interval is non-fossiliferous, due to its intense dolomitization, but for reasons that will appear later, it is correlated as being probably lower Silurian in age.

A transitional zone occurs from 2,870 to 2,884 feet, consisting of dirty, grayish-green, very shaly lime or limy shale and a small amount of very coarse sand which may or may not have been introduced into the hole from the surface. From 2,884 to 2,962 feet occurs a pale green plastic shale, in places dark grayish-green, very "flaky," the exact counterpart, lithologically, of some of the Kinderhook shale, but whereas the Kinderhook shale of this character has embedded spores, this lower shale has embedded microfauna of a different character.

Every sample of this shale interval, from 2,884 to 2,962 feet, shows the presence of fossils. The fossils are minute and fragmentary and impossible to identify specifically at present. Among them are some silicified bryozoa, some fragments suggesting graptolites, and some black, chitinous, highly lustrous annelid jaws. These latter are somewhat similar to annelid jaws picked out of the Spechts Ferry member of the Decorah shale at the outcrop, but differ sufficiently to suggest that they are probably not the Decorah species. The greenish-gray shale interval from 2,884 to 2,962 feet is correlated tentatively as Maquoketa. The 6-inch casing is set at 2,960 feet.

A chert zone (tripoli) and a stratigraphic break occur below the "Maquoketa" shale, from 2,962 to 2,970 feet. From 2,970 to 3,000 feet buff, finely crystalline limestone is present, and from 3,000 to 3,047 feet the limestone is cream-colored to buff, fine and medium crystalline. Fragments of *Rhynchotrema* sp. shells and crinoid buttons were picked out of this limestone, from 2,962-2,965 feet and from 3,022-3,029 feet, and this limestone may be Maysville-Eden in age. If so, the Fernvale limestone, "Viola" of wells in northern Oklahoma, is absent in the Marland, Engle test.

At 3,047 feet, dense buff lithographic limestone was encountered, carrying the typical upper Black River-lower Decorah fauna, consisting of the bryozoan *Rhinidictya mutabilis*, ostracod *Bythocypria*, sp., and gastropod *Bucania* sp.

At 3,065 feet the test encountered sand and deep green shale, lithologically resembling, in every respect, the "St. Peter" or Simpson sediments. The green shale in the Engle test, however, carries upper Black River fossils throughout, among them conodonts and some very plentiful fish scales and plates, from 3,110 to 3,118 feet. The whole limestone, sand, and green shale interval from 3,047 to 3,135 feet is lower Decorah in age.

At 3,135 feet the test entered an erosional zone of Decorah shale and sand, oölitic chert, and sucrose dolomite, which was present down to 3,180 feet.

At 3,180 feet Ordovician "Siliceous lime" (Arbuckle limestone) was encountered. In this test, therefore, beds of Decorah age are resting unconformably on the Arbuckle limestone with the "Wilcox" and "St. Peter" sands absent.

The Arbuckle limestone was 210 feet thick and underlain from 3,390 to 3,420 feet by basal Paleozoic sand. Pre-Cambrian schist detritus was reached at 3,420 feet and penetrated to 3,456 feet, the total depth.

Markham Spier No. 5, center, east line, NW., NE., Sec. 8, T. 22 S., R. 4 E.—This test had Kinderhook shale from 2,390 to 2,545 feet. *Sporangites huronense* is present in the bottom sample, 2,532 to 2,545 feet.

The samples of the next 7 feet, 2,545 to 2,552, consist of white, semi-translucent chert and finely crystalline, "sugary," cream-colored dolomite. No fossils were found in this interval, but it is the producing horizon for the Peabody field. A 1-foot sandy zone, mixed with dolomite and chert, occurs from 2,552 to 2,553 feet, at which depth the test entered dark grayish-green shale carrying many diagnostic upper Black River-lower Decorah fossils. This shale zone is 8 feet thick, 2,553 to 2,561, and the following fossils were identified: the bryozoan *Arthroclema* sp.; gastropods *Bucania* near *Eliptica*, and *Condradella* sp.; and the pelecypod *Ctenodonta* sp. The Decorah shale rested in turn on non-fossiliferous dolomite. The last sample received was of dolomite, at 2,571 feet, but the logs of two granite tests in the Peabody field show what may be the "St. Peter" green shales and sands beneath this dolomite and above the Arbuckle limestone.

Merriam & Skelly, Winters No. 1, center, E. ½, Sec. 17, T. 31 S., R. 12 W.—This test went out of the shale, carrying *Sporangites huronense*,

at 4,430 feet, and encountered dolomitic, cherty limestone. In the sample from 4,440 to 4,450 feet, the bryozoan *Rhinidictya paupera* and a coral, *Chaetetes* sp. were found. Both are upper Black River in age, are found in the lower Decorah shale at its outcrops, and in beds of Black River age in Oklahoma.

The samples below the fossiliferous beds consist predominantly of dolomite with increasing amounts of chert down to 4,480 feet. The proportion of chert to dolomite decreases between 4,480 and 4,512 feet, the base of the dolomite section. No fossils were found in the dolomite below 4,450 feet.

From 4,512 to 4,523 feet the test encountered deep green shale and sand, and from 4,523 to 4,530 feet, where the test was abandoned with a hole full of water, the sample was 100 per cent very irregular, angular sand in which the grains showed secondary enlargement. A very few fragmentary fossils were found in the green shale between 4,512 and 4,523 feet, impossible to identify definitely, but they suggest that this green shale may be Decorah in age.

Merriam & Skelly, Hastings No. 1, SW. corner, Sec. 30, T. 30 S., R. 14 W.—This test had no "Mississippi lime" and no Kinderhook shale, but encountered erosional detritus from 4,485 to at least 4,545 feet. No samples from 4,545 to 4,595 feet were received, but limestone is logged in this interval. The sample from 4,595 to 4,605 feet is of pinkish-white coarsely crystalline limestone. Some of the interval from 4,545 to 4,595 feet may, therefore, be occupied by this limestone, or it may all be detrital material. No fossils are present in the one sample, 4,595 to 4,605 feet, and the age of the limestone is indeterminable at present.

Samples from 4,605 to 4,612 feet are missing, but are logged limestone. At 4,612 feet the test was drilling in dull grayish-green shale, some of which has embedded round and frosted sand. This green shale, mixed with sand and some limestone, is present down to 4,699 feet, and carries Black River-lower Decorah fossils. The interval from 4,612 to 4,699 feet is, therefore, Decorah in age.

The material from 4,699 to 4,740 feet, total depth, is sand and dolomitic limestone, non-fossiliferous, of indefinite Ordovician age. The samples, however, do not contain any of the oölitic chert that is generally regarded as being typical of the top of the Arbuckle limestone. This, at best, is negative evidence.

Philmack, Gregory No. 1, center, SW., Sec. 24, T. 16 S., R. 9 W.—This test had erosional material consisting of reddish-brown vitreous and white chalky chert, and variegated shale, from 3,206 to 3,340 feet.

From 3,340 to 3,408 feet the test was drilling in dark grayish-green shale, mixed with a little sand, between 3,377 and 3,408 feet. Upper Black River-lower Decorah fossils are present in this green shale.

At 3,408 feet the Decorah green shale rested unconformably on the Arbuckle limestone, penetrated to 3,865 feet. Basal Paleozoic sand was present from 3,865 to 3,892 feet, where red and green pre-Cambrian mica-schist detritus was encountered. The total depth, 4,009 feet, was in the schist detritus.

Douglas Oil Company's Stoppel No. 1, center, E. ½, Sec. 25, T. 14 S., R. 11 W.—The 6½-inch casing is set in this test at 3,197 feet, near the base of the Pennsylvanian variegated shale. The "Sooy" erosional zone occurs from 3,200 to at least 3,225 feet. From 3,225 to 3,240 feet the samples contain approximately 20 per cent of light gray, crystalline limestone, as well as the red shale and white chert of the erosional zone. At 3,240 feet the crystalline limestone changes in color to grayish-white and increases in amount to 35 per cent. Between 3,244 and 3,275 feet the grayish-white crystalline limestone predominates in the samples; from 3,275 to 3,290 feet the limestone is pure white and coarsely crystalline. No fossils were found in any of the samples between 3,225 and 3,290 feet, but the limestone in this interval may be Maysville-Eden in age.

At 3,290 feet the test encountered pale green shale; from 3,300 to 3,330 feet the shale was a dull grayish-green; from 3,330 to 3,355 feet the shale was dull green and deep olive-green, identical in color and lithology with the green shales that occur in the middle zone of the "St. Peter" sand of Kansas. The whole shale interval from 3,290 to 3,355 feet carries a very complete and diagnostic assemblage of lower Decorah fossils, upper Black River in age. However, were correlations for this test to be based entirely on lithology, this green shale would be placed much lower in the section than its true stratigraphic position. The fossils identified from this Decorah shale are: *Rhinidictya paupera*, *Arthroclema striatum* (many internal casts), *Arthroclema* sp., *Batostoma fertile*, *Orthis* (*meedsi?*), *Distacodus* sp., *Bucania* (*Elliptica?*), nepionic form, *Bythocypris* sp.

The deep green Decorah shale in this test rested directly and unconformably on the Arbuckle limestone at 3,355 feet, where the test had a hole full of water. The test was abandoned at 3,503 feet in the Arbuckle limestone.

Stearns and Streeter, Blank No. 1, NW., NW., NE., Sec. 14, T. 9 S., R. 16 W.—In this test, the 5³⁄₁₆-inch casing was set at 3,542 feet in the

Pennsylvanian variegated shale zone, the base of which was at 3,553 feet. The casing, therefore, probably did not shut off all the variegated shale cave.

The samples between 3,553 and 3,588 feet consist entirely of white vitreous and white chalky chert with red shale some or all of which may have caved into the hole between 3,542 and 3,553 feet. The horizon between 3,553 and 3,588 feet is correlated with the so-called "Sooy" conglomerate or erosional zone.

Samples between 3,588 and 3,593 feet were missing, but from 3,593 to 3,618 feet (total depth 3,620) some cream-colored dolomite is mixed with the samples. Since the dolomite did not appear in the samples above 3,593 feet, it is entirely possible that the test was drilling in dolomite from 3,593 feet to its total depth of 3,620 feet. Upper Black River (lower Decorah) fossils were picked out of this dolomite from the last two samples, 3,608-3,618 feet.

Stearns and Streeter, Carlin No. 1, SW. corner, NE., Sec. 18, T. 8 S., R. 13 W.—This test found no "Mississippi lime" and no Kinderhook shale, but a basal Pennsylvanian detrital zone occurs from 3,694 to 3,708 feet. The 5 3/16-inch casing is set immediately above the Pennsylvanian variegated shale at 3,505 feet.

At 3,708 feet the test entered cream-colored, finely crystalline and earthy limestone. Unidentifiable fossil casts and brachiopod fragments occur in the samples between 3,708 and 3,724 feet. Some light greenish-gray, very calcareous shale occurs with the limestone. The samples between 3,724 and 3,768 feet are 100 per cent limestone, as above, and the following fossils were found in this interval: *Rhinidictya mutabilis*, *Batostoma* sp., *Callopora*? sp., and some unidentified bryozoa. Grayish-green very limy shale occurs from 3,768 to 3,775 feet; from 3,775 to 3,795 feet occurs grayish-green shaly limestone and cream to buff earthy limestone. *Rhinidictya mutabilis* and some unidentified brachiopod fragments were found in these samples. From 3,795 to 3,801 feet a white, coarsely crystalline, non-dolomitic limestone occurs that entirely resembles, lithologically, the Fernvale ("Viola") limestone in Oklahoma, but is older than the Fernvale limestone. This white limestone in the Carlin test contains crinoidal remains. It is underlain by 19 feet of brown coarsely crystalline limestone, buff and cream-colored very finely crystalline limestone in which some unidentified fragments of bryozoans and ostracods are present. From 3,820 to 3,851 feet the test penetrated light buff to cream-colored medium crystalline limestone which contained fragments of crinoids and large, smooth-shelled ostracods. Light buff

to white, medium crystalline limestone with embedded small dolomite crystals is present from 3,851 to 3,867 feet; cream finely crystalline limestone occurs from 3,867 to 3,935 feet. No fossils are present between 3,851 and 3,935 feet. All of the beds from the base of the detrital zone at 3,708 feet down to 3,935 feet are referred tentatively to the Trenton period. If Trenton in age, they may be correlated as middle and lower Galena, upper and middle Decorah, or both. If they are upper Black River in age, they are to be grouped with the underlying strata.

At 3,935 feet the test entered beds that are predominantly bright green shale, although a little sand and a little limestone are in places mixed with the shale. A suite of beautifully preserved microfauna was obtained, listed with the depths of the samples, as follows: 3,935-3,942, unidentified gastropod, a young pelecypod form resembling *Ambonychia;* 3,942-3,950, *Arthroclema* sp. (internal cast), *Rhinidictya mutabilis*, *Holopea?* sp. (young specimen), *Orthis meedsi*, unidentified gastropod; 3,950-3,953, *Hormotoma gracilis*, *Batostoma fertile;* 3,953-3,960, *Rhinidictya mutabilis*, conodont *Prioniodus* sp., annelid jaw *Lumbriconereites?* sp.; 3,960-3,966, no sample; 3,966-3,967, *Rhinidictya mutabilis*, *Batostoma* near *minnesotense*, *Batostoma* sp., *Arthroclema* sp., *Escharapora* near *subrecta*, *Acrotreta* sp., unidentified gastropod; 3,967-3,973, no sample; 3,973-3,980, *Rhinidictya mutabilis*, *Escharopora* sp.; 3,980-3,985, *Rhinidictya mutabilis*, conodont *Polygnathus* sp., shell fragments of unidentified pelecypod; 3,985-3,990, *Rhinidictya mutabilis*. This green shale, from 3,935-3,987? feet, is upper Black River, lower Decorah in age.

The lowest sample, 3,985-3,990 feet, contains a small amount of cream-colored dolomite and oölitic chert. The test had a hole full of water and was abandoned at 3,990 feet, probably in the top of the Arbuckle limestone.

PETROLOGIC STUDIES OF KANSAS SAMPLES

Heavy-mineral analyses are used for correlating non-fossiliferous sands or for samples in which sand is fairly plentiful. Analyses of this type are particularly applicable to Ordovician sands, inasmuch as these sands have, in vertical sequence, definite and thin zones which are remarkably uniform horizontally for a great many miles.

In the use of heavy mineral analyses for the correlation of sands in the Mid-Continent area several factors must be considered: (1) the component minerals, or different mineral grains in any one assemblage; (2) the percentage in which each mineral is present; (3) the assortment of the mineral grains, that is, whether the grains are all approximately the

same size, or differ greatly in size; and (4) the shape of the grains; whether they are all well rounded, or subangular, or angular; whether some are rounded and some angular, *et cetera*.

In order to apply these analyses with any degree of success, enough analyses of any one horizon must be made to build up a type for that horizon, just as a paleontologist has to know what fossils occur in a given stratum before he can correlate an unknown with the known stratum. Unsystematic heavy-mineral analyses are of no more value than careless paleontologic determinations.

Approximately 311 analyses have been made of pre-Mississippian sands in Kansas. Of these, 57 have been made of sands wholly or partly replacing the pre-Mississippian rocks younger than the so-called "St. Peter" sand, in the following proportions: 11 analyses from 6 wells, of the "Maysville-Eden" limestone; 8 analyses from 3 wells, of the Decorah shale; 38 analyses from 13 wells, of the lower dolomite which lies directly on the "St. Peter" sand. For the "St. Peter" sand, 233 analyses have been made from 44 wells, and 20 analyses of Arbuckle limestone from 12 wells.

Uniform characteristics and heavy-mineral analyses should probably not be expected for the sands that replace the dolomites and shale in the upper part of the pre-Mississippian section, because these sands are not continuous throughout wide areas but are more like beach or shore-line deposits in the more turbid parts of the limestone- and shale-depositing seas. Furthermore, too few analyses have been made to establish a sound basis of heavy-mineral characteristics for the differentiation of these three horizons, so that it would be unwise to attempt, at present, any sweeping generalizations or positive correlations of these beds on heavy minerals alone.

The analyses of the sand that here and there replaces the "Maysville-Eden" limestone above the Decorah shale seem to be fairly consistent in their component mineral percentages. The four prominent minerals are: zircon, approximately 89 per cent; rutile, 7 per cent; tourmaline, 2 per cent; garnet, 2 per cent. There are minor amounts of three accessory minerals.

There is more variation in the analyses of the sand replacing the Decorah shale member, and there are more component minerals. The average of the analyses of this sand is: zircon, 62 per cent; tourmaline, 12 per cent; epidote, 8 per cent; rutile, 7 per cent; barite, 4 per cent; garnet, 3 per cent; tremolite, 3 per cent; with minor amounts of three accessory minerals.

The analyses of the sand replacing the lowest dolomite, lying on the "St. Peter" sand, differ widely both in component minerals and in the percentages in which they are present, as does the stratigraphic position of the sand in the dolomite member. The average of the analyses of this sand is: zircon, 67 per cent; tourmaline, 14 per cent; rutile, 5 per cent; celestite, 3 per cent; barite, 2 per cent; garnet, cyanite, tremolite, and anatase, each 1 per cent; with minor amounts of nine accessory minerals. It may thus be seen that the sands replacing the Decorah shale member and the lower dolomite member are similar in their heavy mineral content, particularly the zircon-tourmaline ratio, and differ from the sand replacing the "Maysville-Eden" limestone member. There is sufficient difference in these analyses so that a distinction could probably be made safely, on the basis of heavy-mineral content, between a sand replacing the dolomite above the shale of Decorah age and a sand replacing the dolomite below the Decorah shale.

The "St. Peter" group is a sand and olive-green shale series that in places occurs immediately above the Arbuckle limestone in Kansas. It can be divided into three main zones that are continuous horizontally for many miles. The uppermost zone is the most limited in extent and to date has been found in a restricted area and in only 7 of the 78 wells from which analyses have been made in Kansas. This uppermost zone is, however, present in practically all of central and northeastern Oklahoma and can be traced into Arkansas and Missouri. This is the true "Wilcox" sand of the Okmulgee district, and the so-called "second Wilcox" of the greater Seminole area. It is characterized by heavy mineral grains that are uniform in size and very thoroughly rounded; and in all of the analyses of true "Wilcox" sand, tourmaline is nearly as plentiful as zircon, or possibly more plentiful.

The middle of the three zones of the St. Peter group is the most extensive in Kansas, and in some parts of the state directly underlies the Kinderhook or Chattanooga shale. Its position is stratigraphically lower than the true "Wilcox" sand, and it is the zone called Tyner by Luther White,[1] but petrographic evidence seems to indicate that it is equivalent, at the outcrops in the Arbuckle mountains, to that part of the Simpson formation which lies below the "Wilcox" sand. This Simpson zone is very extensive in Oklahoma, as well as in Kansas, and occurs directly beneath the Chattanooga shale in the vicinity of Tulsa, Cleveland, Fairfax, Burbank, and other places. In the central part of

[1]Luther H. White, "Subsurface Distribution and Correlation of the Pre-Chattanooga ('Wilcox' Sand) Series of Northeastern Oklahoma," *Oklahoma Geol. Survey Bull. 40-B* (June, 1926).

Oklahoma it is reached by tests only on high structures; in the Seminole City field, for example, a thickness of 558 feet of sediments intervenes between the Chattanooga shale and this Simpson (middle) zone of the "St. Peter" sand in Kansas. In the Simpson zone the heavy-mineral grains are poorly sorted as to size and shape; tourmaline is present only in small amounts; anatase and monazite commonly are present.

The lowest member of the "St. Peter" group occurs directly above the Arbuckle limestone. It is the so-called "Hominy" sand of the oil fields, although, as mentioned by Luther White,[1] the original production near the town of Hominy probably came from the porous top of the Arbuckle limestone. The "Hominy" member has been found to date in only 12 Kansas wells. Several factors contribute to the comparatively limited number of places where this zone has been found in Kansas: (1) being a basal sand, it probably is more or less lenticular and never was deposited as a sheet sand in a wide area; (2) many tests have had a hole full of water in the "St. Peter" sand above this zone, and were abandoned before they reached it; (3) many of the Arbuckle limestone tests have been drilled in areas so high structurally that the overlying "St. Peter" sand was absent. This lowest (basal) "St. Peter" sand zone also is found in fewer places in Oklahoma than are the other zones, probably for the same reasons. The basal "St. Peter" sand zone has larger heavy-mineral grains than the middle zone; the grains are more uniform in size than in the middle zone, but less uniform than in the uppermost zone; and rough, pitted, white and pale pink garnets constitute approximately 12 per cent of the assemblage.

The analyses of sands in the Arbuckle limestone are variable, as would be expected, inasmuch as some of the sand occurs at the unconformity at the top of the Arbuckle limestone and some of it occurs at different zones in the limestone, more as a sandy limestone than a true sandstone. In general, analyses of Arbuckle limestone sandy zones contain less zircon and tourmaline, more barite, and many more accessory minerals than do the analyses of sands replacing the dolomites above the "St. Peter" sand. It is believed, therefore, that the analyses are an aid in the differentiation of the Arbuckle limestone from the other pre-Mississippian dolomites in Kansas.

SUMMARY

1. Correlation of the pre-Mississippian beds in Kansas with those in Iowa may be facilitated by the following observations.

[1] Luther H. White, *op. cit.*, p. 14.

a. Wells which drill beneath the Kinderhook shale in north-central Kansas find a dolomite that may be Silurian in age. Since no fossils have been found in the dolomite its age can not, at present, be established definitely. Studies of the Silurian and Devonian outcrops made during the first and second annual field conferences of the Kansas Geological Society into Missouri and Iowa, discussions of the formations with the geologists from those states present on the field trips, and subsequent laboratory study of the fauna obtained from the outcrop samples, all indicate that this dolomite in Kansas may be correlated with one of the lower Silurian limestones in Iowa and Missouri and is a bed *not* represented in the Hunton terrane of Oklahoma.

b. Some possible annelid jaws and graptolite fragments occurring in a pale green plastic shale beneath the Silurian(?) dolomite suggest the Maquoketa age of this shale. In some places the shale in this interval closely resembles, lithologically, some of the shales of Kinderhook age.

c. Shell fragments in a cream to buff, finely crystalline limestone, in places dolomitic, occurring in north-central Kansas beneath the "Maquoketa" shale, indicate the possible Maysville-Eden age of this limestone. If this limestone is Eden in age, it may be a representative of the upper part of the Galena limestone in Iowa.

d. In the Carlin test and others in the vicinity, beds have been found that have been referred tentatively to the Trenton period on such paleontologic evidence as is at hand. If Trenton in age, these beds may be equivalent to the middle and lower parts of the Galena limestone and the Ion and Guttenberg members of the Decorah shale in Iowa. The Ion microfauna is similar to that of the Spechts Ferry, as is that in the beds in the Carlin test referred to the Trenton, and the faunal control at hand on the Guttenberg member is sparse.

e. The upper Black River, Spechts Ferry (lower) member of the Decorah group of Iowa is the most widespread and the most variable lithologically in Kansas. Beds of this age are much thicker in Kansas than in Iowa, and may consist of siliceous dolomite, light brown finely crystalline limestone, grayish-white coarsely crystalline limestone, pale grayish-green shale, deep olive-green shale, or sand.

f. In north-central Kansas, four beds (the "lower Silurian" limestone, "Maquoketa" shale, "Galena" limestone, and Decorah shale) occur beneath the Kinderhook shale and above correlatives of the Oklahoma Ordovician strata, and in this area the Decorah green shale rests unconformably on the Arbuckle limestone.

In south-central Kansas, one bed only intervenes between the Kinderhook shale and the true "Wilcox" sand of Oklahoma. This one bed is a buff to cream-colored limestone which in some places is dolomitic, and which may be as much as 100 feet thick. A few fossils found in the upper part of this limestone have led to the upper Black River-lower Decorah correlations mentioned for the wells in southern Kansas described in the first part of this paper. A chert zone occurs below the fossiliferous horizon, and below the chert zone the limestone or dolomite is non-fossiliferous.

The writer has not, to date, examined a well that ties the two areas together, that is, one in which a complete sequence has been seen from the lower Silurian(?) limestone, through the Decorah green shale, into the "Wilcox" sand and other Lower Ordovician beds of Oklahoma, into the Arbuckle limestone. There is a striking similarity between the microfauna in the "Eden-Trenton" limestone of north-central Kansas and that in beds of known upper Black River age both in north-central Kansas and elsewhere, so that the identification of a few fossils in the upper part of the pre-Kinderhook-post-Wilcox limestone in south-central Kansas as upper Black River forms is not conclusive evidence as to the age of the whole limestone interval.

The problem of the correlation of the limestone bed that occurs in south-central Kansas directly above the "Wilcox" sand with the proper one of the several pre-Kinderhook-post-Arbuckle beds in north-central Kansas is, therefore, at present conjectural, and two alternatives are presented. (1) This limestone does occur stratigraphically below the Decorah green shale member which has been eroded off in this part of Kansas; the upper part of the limestone is upper Black River in age, and the lower non-fossiliferous part of this limestone may be a correlative of the Platteville limestone of Iowa. If this is the correlation, no equivalent member in north-central Kansas was deposited, since there the Decorah green shale rests on Arbuckle limestone. (2) The limestone beneath the Kinderhook shale and above the true "Wilcox" sand in south-central Kansas may be the same as the limestone in north-central Kansas that occurs above the Decorah green shale and which has there been correlated as Eden-Trenton in age. If this is true, the absence of the Decorah green shale member in south-central Kansas is probably due to non-disposition instead of erosion.

g. If this limestone member is wholly upper Black River in age, there is, in Kansas, no correlative of the Platteville limestone in Iowa.

2. Correlation of the pre-Mississippian beds in Kansas with those in Oklahoma may be aided by the following conclusions.

a. As mentioned in 1, *a*, there probably is no correlative, in Kansas, of the members of the Hunton terrane.

b. If the shale tentatively referred to the Maquoketa is Richmond in age, it is a time equivalent of the Sylvan shale.

c. The writer has, to date, found no fossil evidence of the presence in Kansas of a limestone of Fernvale age, the "Viola lime" of the oil fields.

d. The limestone in Kansas referred to the Maysville-Eden period correlates with some part of the Viola limestone that occurs in the Arbuckle Mountains in Oklahoma beneath the Fernvale member, but which is absent in wells drilled north of the mountains.

e. The upper part of the limestone that is believed to be Trenton in age in the Carlin and other tests in north-central Kansas, probably has no equivalent in Oklahoma. The lower part of this limestone, Trenton(?) in age, may have an equivalent in the "lithographic" limestone (old "lower Viola") of the greater Seminole area and of the Arbuckle Mountains.

f. Beds of upper Black River, lower Decorah age, are found in wells drilled in Oklahoma, and also in the Arbuckle mountain outcrops, below the "Viola" (Fernvale) limestone and above the "Wilcox" sand. As these beds consist of lithographic limestone, dolomitic limestone, green shales, and sands, they are lithologically similar to those of the same age in Kansas, and they carry the same microfauna. These beds are at present referred by Ulrich, provisionally, to the Bromide formation[1] but some of them will be taken out of the Bromide group in Ulrich's forthcoming publication on the Ordovician formations in the Arbuckle Mountains.

g. The "St. Peter" sand of Kansas can be subdivided by heavy-mineral analyses into the true "Wilcox" sand, the underlying Simpson green shales and sand, and the basal "Hominy" sand of Oklahoma. The "Wilcox" sand is absent throughout much of Kansas. The Simpson green shale and sand are present more widely than the "Wilcox," but they are absent on the crest of the "Granite Ridge," on the extension of the "Abilene arch" drilled by Marland in the Engle test, Sec. 12, T. 14 S., R. 1 E., and on the Barton-Russell County "high."

[1]E. O. Ulrich, "Fossiliferous Boulders in the Ouachita 'Caney' Shale and the Age of the Shale Containing Them," *Oklahoma Geol. Survey Bull. 45* (1927), p. 30, fig. 2.

3. There is an angular unconformity in Kansas at the top of the Arbuckle limestone, inasmuch as anything from the Pennsylvanian beds to the "Hominy" sand may be found resting on the Arbuckle limestone.

4. There is an angular unconformity in Kansas beneath beds of lower Decorah age, because these beds may rest on the limestone doubtfully referred to the Platteville, they may rest on true "Wilcox" sand, or on the Simpson green shales and sands, or on the Arbuckle limestone. The Decorah beds occur unconformably above the Arbuckle limestone on part of the west flank of the "Granite Ridge," on the "Abilene arch" extension, and on the north, east, and south flanks of the Barton-Russell County "high."

5. There is an angular unconformity beneath the Kinderhook shale in Kansas, so that the Kinderhook beds may be found overlying any of the pre-Mississippian sediments described in this paper.

6. Some of the pre-Mississippian sediments that are present in one part of Kansas may be absent in another part because of post-Arbuckle uplift and erosion; some may be absent because of pre-Decorah uplift and erosion; some may be absent because of pre-Kinderhook uplift and erosion. There are disconformities in the section and there has been contemporaneous deposition of beds of different lithology carrying the same fossils, particularly during Decorah time.

In order to have a practical working knowledge of pre-Mississippian stratigraphy in Kansas, exactly what beds are present, and their thickness, must be known in all areas. Well-log correlations alone will be of no value in deciding which beds are present in any given area. Suppose, for example, a test records in descending order, below the Kinderhook shale: limestone, shale, limestone. These may be, respectively: (1) lower Silurian(?) limestone, Maquoketa(?) shale, Eden-upper Galena(?) limestone; (2) Eden-upper Galena(?), Decorah, Decorah-Platteville(?); (3) Eden-upper Galena(?), Decorah, Arbuckle limestone; (4) Decorah, Decorah, Decorah-Platteville(?); (5) Decorah-Platteville(?), Simpson, Arbuckle limestone. In different parts of Kansas all of these combinations, and possibly others, are present. In no test seen to date has a complete sequence been found from the Lower Silurian(?) limestone to the Arbuckle limestone. Samples alone will be almost as useless as well logs, because lithologically the Kinderhook, Maquoketa(?), and Decorah shales may all resemble one another, the Decorah shale may look exactly like the Simpson green shales, and the dolomites and limestones above the Arbuckle limestone all resemble one another and the Arbuckle

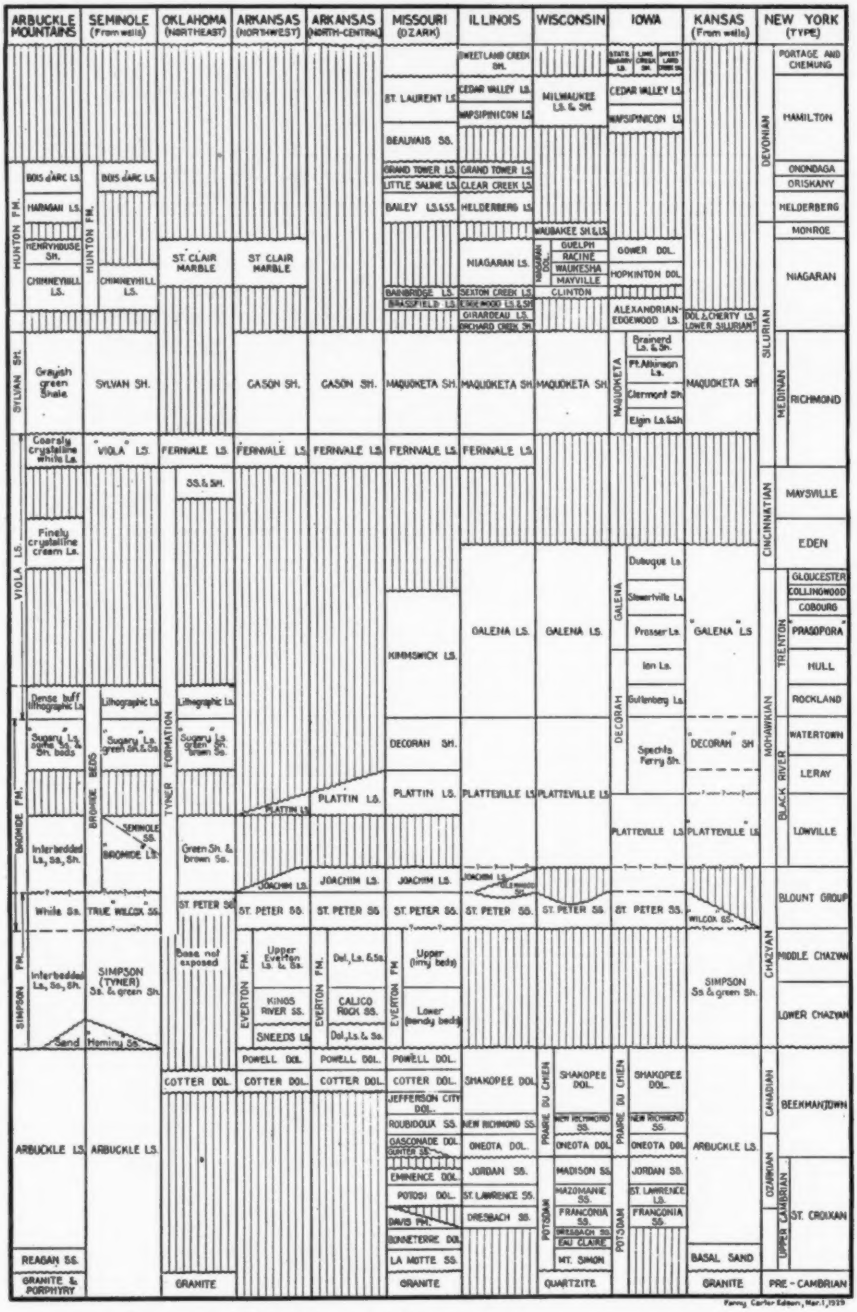

FIG. 1.—Pre-Mississippian correlation chart for Kansas and states near it.

limestone. The microfauna is minute, fragmentary, easily overlooked, and difficult or impossible to identify specifically when found.

Before the distribution and relation of the various pre-Mississippian beds in Kansas can accurately be known, much careful and painstaking work must be done. Any criterion used exclusively for the identification of these beds will, in itself, prove inadequate and misleading, but due consideration of all available information should, eventually, solve the problem.

The correlations discussed in the paper are shown graphically in Figure 1. In this chart, beds that are equivalent in age are placed in horizontal sequence.

ENVIRONMENT OF PENNSYLVANIAN LIFE IN NORTH AMERICA[1]

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ABSTRACT

Plentiful paleontologic and stratigraphic testimony affords basis for interpretation of the life environment of Pennsylvanian time in North America. Excepting a peripheral upland on the east and south, from which sediments were mainly derived, most of the lands were a nearly flat plain of alluviation, bearing swamps and temporary lakes. The climate was subtropic, equable, and humid. Evidence from a variety of sources indicates that the epi-continental seas were exceedingly shallow and fluctuating. Causative factors in the distribution and character of the fossil faunas and in the development of observed stratigraphic features are considered. The hypothesis that the Pennsylvanian formations of the Mid-Continent region were laid down in essentially their present structural attitude is held to be untenable.

Nature of the Record

Evidences of the life of Pennsylvanian time in North America are plentiful and varied. There are not only myriads of fossils in the marine deposits but in many of the formations laid down on land there is a profusion of organic remains.

Life of the lands.—The lands seem to have been well watered, with wide lowlands and swampy areas that bore a rankly luxuriant vegetation. The plant record far surpasses that of any earlier geologic period, and it compares in completeness with that of later times. Amphibians and reptiles, varying in size and degree of advancement, paddled in ponds and rivers and waddled on the land. Large insects crawled about or droned through the air. In fresh waters there were fishes, mollusks, and numerous ostracodes.

Life of the seas.—The shallow seas teemed with life, which, like that of to-day, was probably more abundant in individuals and species than the life of the land. Among plants, there were lime-secreting algæ and doubtless other sorts of seaweeds. Animal life consisted mainly of bottom-

[1]Presidential address, Society of Economic Paleontologists and Mineralogists. Read before the Association at the Fort Worth meeting, March 23, 1929. Manuscript received by the editor, March 2, 1929.

[2]State geologist of Kansas, University of Kansas.

living invertebrates, but there were planktonic and nektonic forms, the latter including fishes, some of which must have attained large size.

Perfection of fossils.—The perfection of preservation of very many Pennsylvanian organisms rivals the best that can be cited from other geologic systems. A fossil fern, recently collected by M. K. Eliashevich near Kansas City, was secured entirely free from the matrix and mounted so as to show every detail of structure. Some of the Pennsylvanian coal balls studied by David White, Noé, and others preserve the microscopic cell structure of plant tissues almost undistorted. The remarkable perfection of fossil crustaceans, insects, and vertebrates of fresh- or brackish-water habitat, as represented in the Mazon Creek nodules of Illinois, the Linton coal of Ohio, and other Pennsylvanian deposits, is well known. As for marine faunas, there are innumerable localities where multitudes of fossils preserve the most delicate surface and structural features, and in some specimens even the color markings may be observed clearly. Examples are the Wayland shale fauna in north Texas, the Wewoka and Boggy formations in Oklahoma, and the DeKalb limestone in eastern Kansas and Missouri. This clear and richly inscribed life record apparently affords all that could be desired for our purpose.

Organic Evidences Concerning Environment

The character and distribution of modern plant and animal societies clearly shows the controlling influence of environment. Presumably the faunas and floras of past geologic time have been controlled by environment in a practically identical manner. In a measure, the lithology of fossil-bearing beds tells its own story concerning environmental conditions, but much of the evidence concerning environment must be sought in characteristics of the fossils themselves. We are guided, therefore, by observations on the structure, habits, and associations of the most nearly related living types. Conclusions reached from such study are generally reliable, but caution must be exercised against making too sweeping and definite deductions.

EVIDENCES OF THE PLANTS

LAND PLANTS

On the lands there is a characteristic variation in the structures and in the grouping of plants with respect to moisture, temperature, soil, hydrogen-ion concentration, and other factors. The general nature of this relation between vegetation and environment is too well known

to require analysis here. It is sufficient for our purpose to point out that the large, thin-walled cells and the general absence of growth rings in woody plants of the Pennsylvanian in North America indicate equable climatic conditions, and that rankness and other features of the vegetation mean ample moisture. David White[1] calls attention to the fact that the nearest relatives of the common and characteristic Carboniferous plants now inhabit humid tropic and subtropic regions. The wide distribution of similar plant assemblages in the Pennsylvanian rocks indicates that at this time there was little climatic differentiation in the regions represented by fossil floras. In the numerous, successive, widespread coal beds there is evidence of low-lying swampy conditions, and among certain of the plants, this is clearly indicated by heterospory and devices for seed flotation.

The common occurrence of roots and stumps *in situ* and the plentiful occurrence at many horizons of almost perfectly preserved delicate leaves —both generally associated with coal beds—show that the original plants grew where their remains are now found. The fire clay beneath coal beds represents the soil on which the peat swamp grew. It is chemically decomposed and Leighton[2] has suggested that the zones recognized in the typical soil profile may be differentiated in some Pennsylvanian fire clays, the thickness of the clay marking the relative length of the time of weathering and residual accumulation of insoluble materials.

The uniformity and very great areal extent of many of the Pennsylvanian coal beds and immediately associated strata can mean only that a featureless swampy plain extended throughout the area of coal deposition. The plain was not necessarily horizontal, for a slope sufficiently low to make movement of water sluggish would, in a nearly flat humid region, permit development of broad swamps. It is conceivable, indeed, that any slight existing drainage may have been so ill organized that open waterways were practically non-existent, the water moving as an extremely sluggish sheet flow. At certain times, as in the Allegheny epoch, coal-forming conditions were more or less simultaneously existent throughout many hundreds of thousands of square miles of North America, reaching from the Mid-Continent to the Appalachian district. It is true that a very slow migration, landward or seaward, of a relatively narrow coal-swamp belt might give rise to a single, very extensive coal deposit, different parts of which would be younger than

[1]David White, "The Origin of Coal," *U. S. Bur. Mines Bull. 38* (1913).

[2]M. M. Leighton, personal communication.

others, but such transgressive, or regressive, continuous coals seem inherently improbable, although possible in exceptional and isolated deposits. The conclusion that widely distributed coals and other deposits are individually essentially contemporaneous is strengthened where similar minor sequences of strata of great persistence are recognized. Thus, the apparent identity of the very widely-persistent Fort Scott ("Oswego") limestone of the Mid-Continent region and the *Triticites*-bearing limestone above the Herrin (No. 6) coal of Illinois and areas farther east, and the suggested equivalence of the "Red" or Lexington coal beneath the Fort Scott in eastern Kansas, Oklahoma, and Missouri, and the Herrin coal of Illinois, seem to indicate coincident and like conditions of sedimentation in the two regions rather than transgressive or regressive sequence of like conditions. If this conclusion accords with the facts, it is evident that a large area in the middle part of the continent must have been almost flat, at first slightly above sea-level (coal-forming conditions), and later slightly below sea-level (marine shale- and limestone-forming conditions).

From the fact that the roof shales of the coal beds in Missouri are mostly lacking in plant fossils but, on the contrary, commonly contain brackish-water or marine shells, David White[1] concludes that the coal swamps of this region were so close to sea-level that submergence, unaccompanied by immediate inwash of sediments, killed the fresh-water plants and left them exposed to decomposing agents. Because of nearness to the sea, he suggests that interruption of coal-forming conditions by subsidence and drowning was more frequent in Missouri than farther east, as in Illinois; accordingly, the western coals are generally thinner.

Several, possibly most, of the sandy and clayey shale formations, such as the Lawrence shale and the Weston shale, which separate the thin limestones of the Pennsylvanian section in the Mid-Continent region, appear to be largely non-marine, interpretable as fluviatile extension of the land into the shallow sea. Twenhofel[1] terms them topset delta deposits. In places there are well-preserved fossil plants, more or less extensive thin coal beds, red zones, and tracks of amphibians or reptiles. These evidences and the notable variation in lithologic character accord with interpretation of them as subaerial deposits. The relatively slight regional change in thickness and the general fineness

[1]David White, "Notes of the Fossil Floras of the Pennsylvanian in Missouri," *Missouri Bur. Geol. and Mines* (2) (1915), Vol. 13, p. 257.

[2]W. H. Twenhofel, *Treatise on Sedimentation*, Williams and Wilkins (Baltimore, 1926), p. 601.

of the clastic materials show the extreme flatness of gradients of the fresh-water currents that furnished means of transportation. In this connection it is noteworthy that deposition of a certain thickness of such material at a given place must have been accompanied by progressive outbuilding into the sea, lengthening the streams and causing aggradation on the land or by progressive slow subsidence of the land approximately balancing the rate of fluviatile deposition. Intercalations of thin fossil-bearing marine shale and limestone, as in the Lawrence shale, mark temporary submergence of seaward parts of the continental sediments.

In most of the Appalachian district, in Arkansas, and parts of southern Oklahoma and north Texas, continental sedimentation predominated in Pennsylvanian time, incursions of the sea being relatively few and brief. The occurrence of conglomerates and prevalence of sandstones, many of them coarse-grained and strongly cross-bedded, characterize several thousand feet of the Pennsylvanian column in these regions. The greater part of these deposits and the associated finer sediments are of fluviatile origin. They contain a few trunks or fragments of *Lepidodendron*, and locally more or less plentiful rolled and macerated leaves and other plant material. The gradient of transporting streams was probably rather small, except locally where the coarsest débris was spread out. The plants of this relatively upland country differ little, in so far as known, from those of the lowlands most frequently flooded by the sea, and except for the lesser prevalence of swampy conditions favoring burial, the environment was little different. No true upland floras of Pennsylvanian age are known and in the nature of conditions governing fossilization and preservation from erosion, they are not likely to be discovered.

Among plants of the land, bacteria are not to be overlooked, the importance of their work, especially in relation to coal-forming, being well recognized. As agents of chemical and physical change in materials of the soil, in fresh waters, and in coal swamps, their action was undoubtedly not different from the present in kind or in significant result.

MARINE PLANTS

In present seas the relative abundance of lime-secreting algæ and various other seaweeds is influenced by depth (light), temperature, bottom conditions, wave agitation, and other factors. These in turn affect conditions of sedimentation and characters of the fauna. In the

shallow waters of the continental shelf there is a distinctly zonal distribution of plants, as regards both kinds and relative abundance.

A considerable but unknown part of the Pennsylvanian limestone was probably precipitated through the agency of marine plants. In the formation of some deposits, like the fresh-water *Chara* marls, the calcium carbonate may accumulate on the sea floor in finely divided form without evidence of mode of deposition. In other deposits, as those of the alga *Halimeda*, or the Pennsylvanian *Osagia*, there is a definite structure. The Lonsdale limestone in Illinois, and the Amazonia, Bethany Falls, and other limestones in Kansas and Missouri exhibit a characteristic mottling and nodular weathering that is almost certainly assignable to algal origin. With this conclusion David White[1] agrees. These algal limestones are, in general, markedly barren of invertebrate remains, a condition which is strikingly characteristic also of the Muav (Upper Cambrian) algal limestone of the Grand Canyon district. The conditions that favor deposition of lime by these plants thus seem to constitute an unfriendly environment for marine invertebrates. The lack of argillaceous sediment in the algal limestones indicates clear water, and the prolific growth of algæ probably signifies shallow water. The larger magnesium content of some of these beds may result from precipitation of magnesium carbonate by the algæ,[2] for the algal growths are commonly strongly magnesian and the surrounding matrix is calcareous; nevertheless, it is possible that selective dolomitization of the algæ, syngenetic or epigenetic, is responsible for the mottling.

The wide distribution of bacteria, the physical and chemical conditions of their environment, and the product of their activities are subjects that have profound geologic importance, and fortunately problems in this field are now being attacked by qualified specialists. Conditions affecting decomposition through the agency of bacteria, precipitation of lime and other rock-forming materials, and a variety of chemical reactions induced by bacteria have undoubtedly been the same in the geologic past as in the present, and definite knowledge in this field will make possible more precise interpretation of the geological record.[3]

Various types of marine bacteria seem to be effective as precipitating agents of calcium carbonate, but the environmental conditions and bio-

[1] *Op. cit.*, p. 257, and personal communication.

[2] W. H. Twenhofel (*Treatise on Sedimentation*, p. 220) shows that some calcareous algal secretions contain as much as 25 per cent magnesium carbonate.

[3] George A. Thiel, "A Summary of the Activity of Bacterial Agencies in Sedimentation," *Rept. Com. on Sedimentation, National Research Council*, Reprint and Circular Series No. 85 (1928), pp. 61-77.

chemical reactions which govern this precipitation are not clearly understood. The formation of oölites, such as occur at several horizons in the Pennsylvanian marine deposits of North America, is probably the work of bacteria. The lime is not only precipitated concentrically around minute nuclei to form the oölite granules, but is commonly spread as a coating on invertebrate shells of all kinds.

A very interesting type of deposit among Pennsylvanian formations is the black, finely laminated and highly fissile or platy shale which is generally only a few inches or a few feet in thickness but seems to be widely spread horizontally. Examples are the "shale gas" horizon between the lower and upper Fort Scott limestones, the Galesburg shale of the Kansas City formation, parts of the Heebner shale of the Oread limestone, Queen Hill shale of the Lecompton, and Mission Creek shale of the Deer Creek.[1] The association of these black shales with marine beds, their wide distribution, notwithstanding thinness, and the occurrence of marine fossils indicate origin in the sea. The black color is due to finely divided, disseminated iron sulphide and to much partly decomposed plant matter. An acid and toxic environment is indicated by the nature of the plant débris, the presence of sulphides, and the restriction of the scanty invertebrate fauna to a few generally depauperate mollusks, linguloid and discinid brachiopods, with addition of *Ambocoelia* and other resistant types, conodonts, and planktonic organisms. The plants may represent sea weeds, but may also include land-derived types. The conditions suggest stagnation not unlike that of the coal swamps and quiet, undisturbed sedimentation of a humous muck. Extremely shallow water, with sunlight promoting abundant plant growth and aiding in partial decay, with too little depth for circulation and effective wave or tidal agitation, seem to offer the environment required. The quiet of moderately deep water, below the zone of effective wave agitation, lacks other environment requisites unless, conceivably, the peculiar conditions of inclosure and lack of circulation reported in the Black Sea existed. Under this hypothesis the repeated changes from black fissile shale to normal limestone and shale deposition and the intercalation of subaerial sediments, makes necessary the unwarranted assumption of very frequent, considerable up-and-down movements of the sea floor. At the horizon of the Fort Scott limestone there is a widespread coal that is overlain by black shale with marine fossils, limestone, more black shale, more limestone, and shale with

[1] G. E. Condra, "Stratigraphy of the Pennsylvanian System in Nebraska," *Nebraska Geol. Survey, 2nd ser., Bull. 1* (1927).

land plants. These changes in conditions of sedimentation and environment were surely accomplished without great change of relative elevation of the sea-level.

The carbonaceous material of the "black slate" overlying coal beds is interpreted by White[1] as probably derived from the peat, that is, coal itself, by reworking of the very shallow sea that drowned the coal swamp. This may be true if the dark, thinly stratified carbonaceous muds immediately overlie coals, but it seems scarcely applicable to the numerous widely distributed black muds between limestones and intercalated in marine shales where no coal occurs.

EVIDENCES OF ANIMALS

LAND ANIMALS

Animals of the land and of the fresh- and brackish-waters are, in general, readily recognizable, and they afford adequate basis for identification of environment. Pelecypods such as *Naiadites*, *Anthracomya*, and *Carbonicola*, and various gastropods are recognized as non-marine by their general similarities to such modern fresh-water mollusks as *Lampsilis* and *Unio*, by absence of marine genera in association with them, and by stratigraphic evidences that the fossil-bearing beds and adjacent strata were laid down by non-marine agencies. Some of the deposits, especially such fresh-water limestones as occur in the Conemaugh, probably were laid in temporary broad shallow lakes. Tracks and skeletal remains of land vertebrates are indicative of land conditions, but evidences of the exact nature of the environment are commonly lacking.

MARINE ANIMALS

Marine faunas show marked variations in response to environment. In varying degree bottom-living organisms are affected by factors of temperature and depth (partly interrelated), salinity, food supply, agitation of the water, and probably most important, the character of the bottom. Petersen[2] and others have made carefully-detailed investigations of the variations in modern shallow-water marine faunas and have demonstrated the controlling influence of environment. Pennsylvanian bottom-living species seem to show a similar response to their surroundings.

[1]David White, *op. cit.*, p. 256.

[2]C. G. J. Petersen, "The Sea Bottom and its Production of Fish Food," *Danish Biol. Sta. Rept.* 25 (1918); "A Brief Survey of the Animal Communities in Danish Waters," *Amer. Jour. Sci.*, (5), Vol. 7 (1924), pp. 343-54.

Foraminifera.—*Foraminifera* are mainly controlled by temperature, the greatest abundance of species and individuals and the maximum size of tests occurring commonly in warm, shallow waters. In cold waters there is a tendency toward smaller species and a dominance of forms with an arenaceous test. Since increase of depth is generally marked by increasing coldness, there are noteworthy dissimilarities in foraminiferal faunas from different depths. According to Cushman and Waters,[1] the smaller *Foraminifera* of the Pennsylvanian rocks are mainly types having walls composed of agglutinated particles, this character being interpreted as a mark of the primitive development of the class rather than an indication of cool waters. Galloway and Harlton[2] assert that most of the supposed arenaceous shells of this age are really calcareous. Certainly the profusion of fusulinids throughout most of Pennsylvanian time suggests warm, shallow seas, for these very large calcareous types correspond with the subtropic and tropic giant benthonic *Foraminifera* of later geologic time. In the lower Pennsylvanian strata *Fusulinella* is locally common, but rarely composes a large part of the fauna. In beds of middle and late Pennsylvanian age *Triticites* and *Fusulina* are important rock builders, in many places crowding out almost all other forms of life.[3]

Very many well-preserved *Foraminifera*, such as appear in most of marine Pennsylvanian deposits, indicate a relatively quiet environment, unagitated by strong wave action. Disturbance of bottom sediments by waves depends on various factors, most important of which are depth of water and the strength and fetch of winds. Beneath broad stretches of very shallow water the bottom is subject to little if any greater agitation than at depths near the limit of wave motion in moderately deep water, for the size of the very shallow water waves is never large. Consequently, depths ranging from 5 to 50 feet may, under certain conditions, afford surroundings quite as favorable to foraminiferal population as depths of 400 or 500 feet and they may be even more favorable.

In many of the black fissile shales of the Pennsylvanian, which, as already noted, indicate deposition in acid, toxic waters of poor circulation, there are a few species of *Foraminifera*. These are almost altogether arenaceous forms which by their flattened character indicate that the

[1] J. A. Cushman and J. A. Waters, "Some Foraminifera from the Pennsylvanian and Permian of Texas," *Contrib. Cushman Lab. Foraminiferal Research*, Vol. 4 (1928), pp. 31-55.

[2] J. J. Galloway and B. H. Harlton, "Some Pennsylvanian Foraminifera of Oklahoma, with Special Reference to the Genus *Orobias*," *Jour. Pal.*, Vol. 2 (1928), p. 339.

[3] C. O. Dunbar and G. E. Condra, "The Fusulinidae of the Pennsylvanian System in Nebraska," *Nebraska Geol. Survey* (2), Bull. 2 (1927).

inner body wall and the cementing material of the grains in the test was chitin, like that of modern *Foraminifera* existing in a similar environment.[1]

Sponges.—Modern sponges thrive best in the warm, clear waters of shallow seas. Except very locally, as in parts of the Plattsburg limestone of eastern Kansas, this group of invertebrates is not important in the Pennsylvanian marine faunas. Since the species known occur chiefly in limestones, it is suggested that these limestones are deposits of warm, clear, shallow seas.

Corals.—If the habitat of the ancient corals was essentially the same as that of Recent forms, this group furnishes more definite evidence of warm, shallow waters. A preponderant part of the modern corals live at depths less than 150 feet, many prolific growths of reef-forming species occurring almost at the surface. The most favorable temperature for coral growth is 73°-78° F., 68° being the lower limit for reef corals. Pennsylvanian coral reefs occur in some of the limestones, such as the Fort Scott (*Chaetetes* reefs), Lecompton (*Campophyllum-Syringopora-Aulopora* reefs), and Gunsight (*Campophyllum* reefs), and conditions favorable for coral growth were evidently present intermittently throughout most of the area occupied by the sea in North America. In formations like the Fort Scott and Lecompton limestones, corals are not only locally very plentiful but they are extremely widespread; in others, such as the Hertha and Oread limestones, there is a profusion of corals in some localities and not a specimen in others. Small horn corals, including species of *Lophophyllum* and *Axophyllum*, are not uncommon in shale faunas; examples are the Wayland shale of Texas, Wewoka formation of Oklahoma, and Chanute shale of Kansas and Missouri. Judged by their distribution these solitary corals were able to endure a muddy environment better than *Campophyllum*, *Chaetetes*, and other reef-forming types.

Bryozoans.—Bryozoans of present seas are most abundant in moderately warm, shallow waters where there is a shell or rock bottom; they are less common in muddy surroundings and rare in sandy areas, but the erect forms in particular may grow attached to sea weeds. They thrive in gentle to fairly brisk currents. Pennsylvanian bryozoans are common in most of the limestones but are most plentiful and best preserved in the shaly limestones and limy shales. In places they occur in remarkable profusion. The nature of the enclosing sediments, perfection of preservation of delicate structures, and association with numerous crinoids in several noteworthy collections, indicate quiet water of sufficient depth and freedom of movement to provide favorable

[1] J. A. Cushman and J. A. Waters, *op. cit.*

circulation but not subject to strong waves or currents. Presence of many shallow-water invertebrates and interdigitation of bryozoan-bearing beds and continental deposits may be interpreted as signifying depths of a very few fathoms rather than several tens of fathoms.

Brachiopods.—The brachiopods are typically shallow-water creatures, only a few ranging beyond the edge of the continental shelf to depths of more than 600 feet. Inarticulates seem to favor the very shallow waters (maximum, 100 feet), and here also the articulates increase in number and in thickness of shell. Forms with functional pedicles require solid objects for attachment; accordingly, orthoids, rhynchonelloids, terebratuloids, and spiriferoids of the Pennsylvanian were adapted to a hard or shelly bottom. These brachiopods are most plentiful in the limestones where shell forms of various sorts were abundant, but they also occur commonly in shales, in which environment anchorage was doubtless furnished by other invertebrates. Productoids, linguloids, and *Derbya* were at home on muddy bottoms. *Chonetes* is exceedingly plentiful at different horizons in argillaceous and calcareous shales. It has been thought that *Productus* lived with the pedicle valve on the under side, its spines, some of which are 3 or 4 inches long, serving as means of fixation. Muir-Wood[1] has recently advanced reasons for concluding that in life these shells had a reverse position, and the writer's own observation of the orientation of many specimens in place, including those where there is best evidence of undisturbed conditions, sustains the latter view. Studying the distribution and character of *Derbya* shells in Pennsylvania of West Virginia, Price[2] has shown that specimens are most robust in light-colored sediments, shale, and argillaceous limestone; they are medium to large in darker-colored calcareous or sandy shale and limestone; and they are smallest in black shale beds. Linguloid and discinid brachiopods of the present day seem to prefer waters not only shallow but subnormal in salinity. Shells of this type in the Pennsylvanian are characteristically associated with the black platy shale zones already considered as deposits of very shallow, probably brackish waters, acid in nature because of accumulating humous materials and poor circulation.

Some species of brachiopods are very plentiful at certain localities but rare or absent in other places in the same bed, notwithstanding

[1] H. M. Muir-Wood, "The British Carboniferous Producti. II. Productus (*Sensu stricto*), Semireticulatus and Longispinus groups," *Great Britain Geol. Survey Mem. Pal.*, Vol. 3, Pt. 1 (1928), p. 26.

[2] W. A. Price, "Maximum Size of West Virginia Derbyas as Influenced by Sedimentation," *West Virginia Geol. Survey Webster County Rept.* (1920), pp. 545-51.

apparently identical environments. A striking example is found in the occurrence of *Enteletes hemiplicata* in the Stanton limestone of eastern Kansas; this shell is not very common at most places, but near Eudora the lower bed of the Stanton contains millions of beautifully preserved specimens crowded together. This irregularity of distribution is analogous to conditions observed in parts of the present shallow seas, where, although environment appears to be the same, there are areas populated by certain species in great numbers, separated by areas in which they are few or lacking. The causative factors of such conditions may be very obscure, and where crowding of like organisms produces competition in securing food and possibly even in finding sufficient room for growth, resultant conditions must be distinctly less favorable for the individual.

Crinoids.—Crinoids are relatively delicate echinoderms, the stalked forms requiring sufficient depth to avoid destructive agitation by waves. Modern species range from moderately shallow waters to depths of approximately 14,000 feet. Plentiful crinoidal remains in some of the Pennsylvanian limestones and limy shales, associated with various invertebrates that are characteristic of shallow seas, denote a fair degree of quiet on the sea bottom, but this may be the quiet of very broad, very shallow water bodies where waves, though effective as transporting agents, can not greatly disturb the bottom. The fact that crinoid-bearing beds are commonly interstratified with sediments that are clearly indicative of slight depth, and even with deposits that represent emergent conditions, is sufficient proof that deep water was not required by these organisms.

Echinoids.—Echinoids, which are represented by very numerous plates and spines in several Pennsylvanian formations, are at home in the shallow seas, being found on solid bottom, in muddy areas, and on sand. They are most common in warm, clear waters, a fact that accords with their chief development in Pennsylvanian limestones. The echinoids exhibit a tendency to concentrate in local areas.

Pelecypods and gastropods.— Among the mollusks, pelecypods and gastropods show great variation in habits and they are adapted to many sorts of environment. In the sea, shallow-water forms are more abundant, generally larger and more heavily shelled than deep-water types. They are common on hard or shelly bottoms but, unlike many of the invertebrates, are able to cope with the rather unfavorable surroundings of soft mud and they even occur in sandy areas. Consequently, the faunas of shales and sandy sediments are commonly marked by a dominant molluscan element. It may be noted, however, that according to lists

of Beede and Rogers, Girty, and Moore, a larger number of species of pelecypods and gastropods is known from Pennsylvanian limestones than from shales or sandstones; yet only in a few limestones, such as the Winterset, DeKalb, Iatan, and Howard, does the number of mollusks noticeably exceed that of molluscoids. In certain beds in these and other stratigraphic units, molluscan dominance is associated with the occurrence of oölite, and the rather unfavorable character of oölite-making environment as regards most invertebrates is presumably shown by a general tendency of the oölite fauna toward dwarfism and reduction in numbers of different groups. Environment alone, however, is scarcely sufficient to account for the sudden appearance, as in the DeKalb limestone, of a host of strange species and genera of mollusks. For example, several species of *Pseudomonotis* abruptly make their advent in the DeKalb and then disappear until late in the Pennsylvanian and in the Permian when they are common; they are forerunners of the *Monotis* group which is characteristic of the Triassic.

Cephalopods.—The adaptation of cephalopods to their environment and the effect of their mode of life on structural features have been discussed in some detail by Dunbar.[1] It seems most probable that there were both free-swimming and bottom-living kinds, and among the latter there were forms living in clear-water, lime-depositing areas, on muddy bottoms, and on sands. Pennsylvanian cephalopods are most common in the limestones, but there are many specimens in shale and these shells are rather plentiful in a few sandstones. The concentration of considerable numbers of these shells in relatively small areas and restriction of certain cephalopod faunas to given stratigraphic horizons suggest that the Pennsylvanian species were dominantly benthonic in habit and they may have been more than ordinarily susceptible to changes in their environment. It is interesting and possibly significant that while orthocerans and nautiloids are common and very widespread in the North American Pennsylvanian interior seas, the ammonites of varied sorts that flourished in Texas are virtually unknown elsewhere. Faunal differences of this nature may, however, be the result of restricted intercommunication.

Trilobites.—Among the crustaceans, there is not very important testimony regarding habits of the Pennsylvanian trilobites nor do they furnish much evidence as to environmental conditions. They are decidedly on the wane. The large pygidia and cephalons indicate that

[1]Carl O. Dunbar, "Phases of Cephalopod Adaptation," in *Organic Adaptation to Environment*, Yale Univ. Press (1924), pp. 189-223.

movement was restricted to crawling on the sea bottom and occurrence of fossil remains mostly in limestones shows that the trilobites preferred clear water.

Ostracodes.—Ostracodes are widely distributed, varied, and in many places extremely abundant. They include both free-swimming and bottom-dwelling types, and adaptations to almost all types of environment are found. Some forms can live indefinitely in foul, stagnant waters. The beautiful preservation of delicate structures in a host of Pennsylvanian fossil ostracodes indicates that the shells were not rolled by waves nor carried by currents sufficiently to produce wear. The fact that many ostracode faunules of successive rock layers of different lithologic character are notably unlike is almost certainly in part due to environment. Since the shells are very light and small it is readily possible that benthonic species may under some conditions be spread to other areas and like the planktonic forms these may be useful in correlating unlike facies. Because of their abundance, wide horizontal range, and generally short vertical range, the ostracodes are satisfactory zone fossils.

Vertebrates.—Remains of vertebrates are not very common in the marine Pennsylvanian rocks of North America, but selachian teeth and a few ichthyodorulites are found. Some of the latter are rather large, indicating fish of considerable size. The writer collected a specimen from the Wayland shale of north Texas, probably a head spine, approximately 2 inches thick and a foot long. Fish remains most commonly occur in the limestones, but inasmuch as fishes are free swimming they are of little importance as evidences of environment. Conodonts, which are now interpreted as largely piscine in nature,[1] are found in the black, fissile shales where in some places they are plentiful. The more or less toxic, probably brackish character of the water in which the black shale is believed to have been deposited, makes an environment unfriendly to most life, very different from that of the open shallow seas. If this interpretation is correct, the conodonts may represent organisms specially adapted to the foul conditions, and, by reason of them, somewhat dwarfed, or possibly restricted in life to the near-surface better aerated water. At all events, the conodonts are definitely associated with this particular environment.

STRATIGRAPHIC EVIDENCES OF ENVIRONMENT

Under this head may be grouped observations bearing on the environment of Pennsylvanian life based on the physical characters, dis-

[1] E. O. Ulrich and R. S. Bassler, "A Classification of the Tooth-like Fossils, Conodonts, with Descriptions of American Devonian and Mississippian Species," *U. S. National Mus. Proc.*, Vol. 68 (1926), pp. 1-4.

tribution, thickness, inter-relations, and paleogeography of the rock formations.

ENVIRONMENT OF LIMESTONE FAUNAS AND FLORAS

There are several types of limestones in the Pennsylvanian of North America; in fact, almost every bed presents distinctive lithologic characters of some sort. Algal limestones, differing probably because of differences in character or in relative importance of species of algæ represented, are almost or quite lacking in invertebrate remains. Oölitic limestones, possibly formed through the agency of bacteria, commonly contain a somewhat plentiful, strongly molluscan fauna that may be dwarfed, and exhibit in their prevalent, strong cross-bedding evidences of shallow water and of currents. Other limestones, which may be classed as the normal type, show all degrees of impurity; textures ranging from very fine and earthy to rather coarse-grained and crystalline; bedding very thin to massive and very regular to extremely irregular; and thicknesses from less than an inch to scores of feet. These variations indicate differences in environment, but their exact significance is not well understood. It is a striking fact that many peculiarities of lithology and fauna that characterize a limestone are very constant throughout a large territory and that these peculiarities are not exactly repeated. Examples are the coquina-like Falls City bed with plentiful minute mollusks, ostracodes, and other forms, and the Brownville bed characterized by color and texture and by very plentiful occurrence everywhere of *Marginifera splendens*. It is not certain that essential factors in physical environment varied notably during deposition of these beds, for changes in the biota due to other causes might be a controlling character. There is evidence that the limestones were deposited in moderately shallow and very shallow waters, that is, at depths probably not more than 300 feet or less than 10 feet. There is no known indication of deep waters, that is, deeper than 600 feet. The waters were essentially clear and moderately warm.

To what extent the action of sea-bottom scavengers, worms, holothurians and other animals that pass the sediments through the alimentary tract, modifies and comminutes the limy materials, and what environmental conditions favor this working and re-working of sediments by organisms, is not known. Obviously, unbroken shells of any size should be unaffected by scavengers, and this may explain why productid and other shells commonly occur scattered promiscuously through an even, fine-grained rock, like plums suspended in a pudding. An excellent example is the lower Fort Scott (cement rock) limestone. On the con-

trary, the common occurrence of perfectly-preserved delicate microfossils implies that the fine materials of the limestone have been little re-worked, and suggests that the nature of original sedimentation is chiefly responsible for textural characters.

The composition by species of a few typical Pennsylvanian limestones is shown in the accompanying diagrams. These show that molluscoids

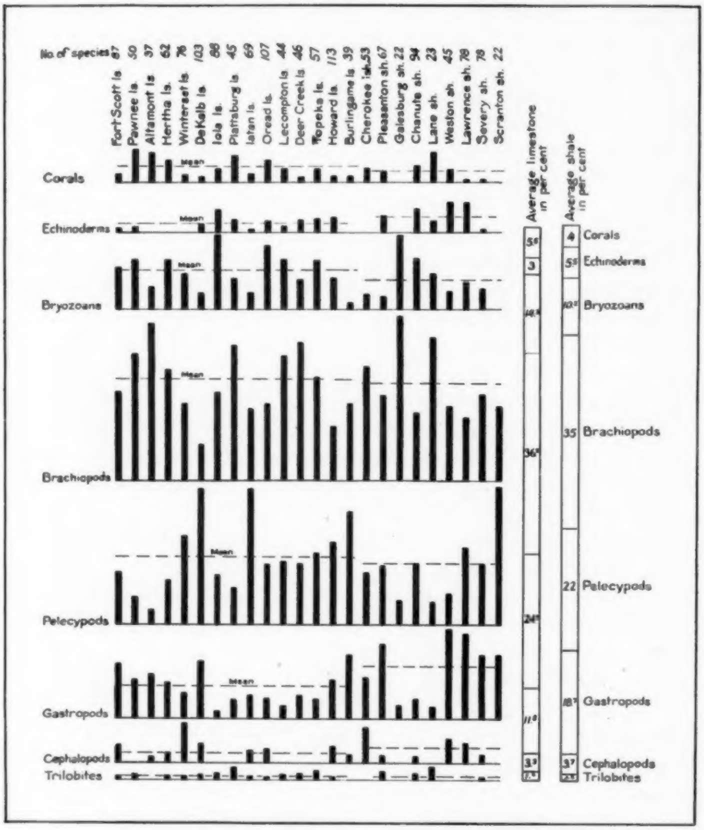

FIG. 1.—Composition of Pennsylvanian limestone and shale faunas of Kansas, based on lists of Beede and Rogers. The number of species reported from each unit is given at the top of the diagram; the graphic representation is in each case by per cent. The fact that the average faunal composition of the limestones and shales is so nearly identical *by species*, may in part result from inclusion of minor, very fossiliferous shale beds in the limestones, and of limestone beds in the shales.

generally are dominant, although mollusks may be nearly as important. The numbers of individuals may reflect environmental conditions much more accurately than number of species. There are limestones with billions of specimens of *Triticites* and almost no other megascopic fossils; *Chonetes verneuilianus* may comprise 95 per cent of a fauna according to number of individuals but only 2 per cent by species.

Limestones regarded as of fresh-water origin occur in parts of the Appalachian and possibly other districts. Examples are the rather widespread Summerville, Ewing, and Pittsburgh limestones in the upper Conemaugh of Ohio,[1] and corresponding beds in West Virginia and Pennsylvania. The fauna consists of minute invertebrates, chiefly *Spirorbis* and ostracodes, of fish teeth, plates, and bones, and of rare reptile bones. These limy beds were presumably deposited in broad, temporary, shallow lakes.

ENVIRONMENT OF SHALE FAUNAS AND FLORAS

The shales of Pennsylvanian age naturally exhibit a very wide range of lithologic and paleontologic characters. To a certain extent they may be classified directly on the basis of environment, those containing marine fossils being obviously marine and those lacking marine organisms but containing land plants or animals being clearly continental. There remain many deposits of shale that seem to be devoid of organic remains, the mode of deposition being determinable, if at all, only on lithologic and stratigraphic characters.

The marine shales are mainly grayish, yellowish, bluish, or dark-colored, but may be red, green, brown, or of other colors. They may be clayey, sandy, or limy. The deposits may be very uniform or there may be regular or irregular intercalations of shaly or non-shaly sandstone or limestone. It can not be attempted here to analyze in detail the various environmental conditions that are indicated, and data are inadequate for satisfactory study of the biologic aspects of these environments. It may be observed, however, that the known shale faunas are typically those of shallow waters, and that the muddy sea bottom is generally much less favored by most marine organisms than the hard or limy bottom. Where fossils are plentiful the number of species represented is commonly small. The normal light- or dark-colored fossiliferous marine shales were deposited in water sufficiently deep to provide fair circulation, but this could be a very few feet if growth of vegetation did not clog the water. The probable conditions of formation of the black

[1] D. D. Condit, "Conemaugh Formation in Ohio," *Ohio Geol. Survey* (4), Bulls. 17, 20, 23, 37 (1912).

shales have been considered; perhaps the only difference between these and some of the so-called normal types may be restricted circulation due to abundant plant matter, or the presence of a large quantity of humous materials derived from drowned coal swamps.

Non-marine shale deposits may contain somewhat plentiful fossil plants, fresh-water invertebrates, or land vertebrates. They may be associated with coal beds representing swamp conditions. Generally the non-marine shales are less uniform in character than the marine. They were deposited by streams and in temporary shallow lakes of various shapes and sizes. Most of the streams had very gentle gradients, and built up in the area of sedimentation a very broad plain composed of coalescent, nearly flat-topped fans. Such a plain, pushing outward into the sea, is identical in character with the topset beds of a delta, but if the adjacent sea is so shallow that foreset beds do not develop, the sedimentary structure is not typically deltaic.

There are not a few Pennsylvanian shale deposits that at least locally seem to be devoid of organic remains. Some of these, especially somewhat irregularly-bedded, sandy, micaceous shales, are almost surely non-marine, for they occur in parts of the section that are wholly or almost wholly continental and are geographically remote from known contemporaneous marine deposits. In other places, as in most of the Mid-Continent, where sea and land conditions alternated repeatedly, there may be difficulty in determining precisely the mode of origin. Absence of fossils in subaerial deposits is commonly due to complete oxidation, or decay and solution of the organic material, either prior to burial or shortly after burial; perviousness of sediments, alternate wetting and drying, and possibly conditions specially favorable to bacterial decomposition may be important factors. Absence of fossils in marine deposits is generally due to inhospitable environment or to action of scavengers. The Cherryvale and the Lane shales of eastern Kansas are in many places unfossiliferous; they are regarded as marine because locally they contain marine fossils, consist mainly of very uniform, thinly laminated dark blue shale, and in places include thin beds of limestone. The Weston and Kanwaka shales, likewise unfossiliferous in many exposures, seem to be mainly continental, for the locally occurring fossils consist of land plants and tracks of vertebrates, and yellow-brown or variegated sandy shale and lenticular sandstone are common types of deltaic deposits.

Finally, the more or less complex dual origin of some shale deposits should be noticed. The Lawrence and Pleasanton shales may be cited as

examples, but there are many others, for possibly the majority of Pennsylvanian shales as now defined stratigraphically comprise both marine and non-marine strata. Transition from one type to the other occurs both laterally and vertically, and it is clear that the changing relations of sea and land at shortly succeeding time intervals may be intricately complex. Since identifiable shore-zone features are lacking, it is probable that the flat, alluvial land graded without change of slope at the sea margin into equally flat barely submerged parts of the sea bottom; and under such conditions very slight oscillations of sea-level or local variation in land elevation due to aggradation or down-sinking would produce considerable fluctuations of the strand line without leaving record of the change except in the nature and organic content of the sediments themselves.

ENVIRONMENT OF SANDSTONE FAUNAS AND FLORAS

From a quantitative standpoint, sandstone is an important constituent of the Pennsylvanian rocks of North America, and for present purposes the locally very considerable deposits of grits and conglomerates may be included with the sandstones. However, neither on land nor in the sea is a sandy environment very well adapted to the requirements of plants or animals, and conditions are unfavorable as regards preservation of organic materials that may be buried in sand or gravel. Consequently, most sandstones are barren of fossils.

The sandstones and conglomerates deposited on the lands of Pennsylvanian time are almost exclusively the result of stream work. Wind-blown sands may occur, but they have not been recognized; and there is little definite indication of transportation and deposition by lake currents. The sandstones are commonly irregularly stratified and cross-bedded. Occurrence in the form of broad sheets and lenses of irregular thickness suggests the spreading out of stream-borne materials seen in compound alluvial fans. The rare fossils in these deposits consist of lepidophyte and calamite trunks, a few leaves and other plant matter, and in a few places tracks of land vertebrates. The environment probably differed somewhat, but not greatly, from that of the densely green-clad swampy lowlands. Water flowed more rapidly, streams had slightly steeper gradients, and the land was probably better drained.

The marine sands occur as somewhat extensive, wave- and current-spread sheets and lenses, many of them thin and discontinuous, others several tens of feet in thickness. They may be widely marked by ripples and by cross-bedding. Scarceness of fossils is due chiefly to the

shifting character of the sea bottom, which discourages occupation by most invertebrates. Locally, however, fossils are surprisingly plentiful, as in a sandstone near the base of the Atoka formation at Clarita, Oklahoma. In the Pennsylvanian of central and southwestern Colorado, New Mexico, and Utah there are numerous limy, arkosic sandstones and grits that alternate with limestones. Some of the limestones contain numerous fossils, but most of the sandstones are unfossiliferous. Unless there were very frequent physical changes of unknown character in this region, the sandstones must have been laid down under approximately the same conditions as normal limestones.

ENVIRONMENTAL SIGNIFICANCE OF MINOR STRUCTURAL FEATURES

Cross-bedding.—Cross-bedding is commonly observed in the sandstones and oölitic limestones, but not in other deposits, which are characteristically bedded or laminated horizontally. The cross-bedding, of course, clearly indicates action of currents and if made under water the depth must be shallow. Are currents absent where cross-bedding is lacking? Does horizontal lamination of beds indicate deeper, quieter water? Answer to these questions rests largely on observation of the manner in which currents transport coarse and fine particles, dragging or rolling the former along the bottom but carrying the latter in suspension. Under the first condition a bar or dune probably forms, and cross-lamination is developed as leeward building progresses. In the second, there is no such local accumulation of a wedge of sediment, building outward in the direction of current movement, and the fine particles, carried along above the bottom, are spread more widely and, as the currents weaken, settle evenly. Current action may be effective in spreading and in eroding fine sediment but it does not develop cross-bedding. Since horizontally laminated strata commonly occur immediately beneath and above a cross-bedded layer, it might be concluded *a priori* that difference in the depth of water under which the two types of beds formed is improbable. It is also very possible that conditions of movement in the water were not essentially different. These structural features depend on the nature of the materials that are being deposited. An evenly laminated shale or a limestone may be laid down in waters quite as shallow and as much affected by currents as that in which a cross-bedded sandstone or oölite occurs. In fact, a fine shale or limestone may form in water so shallow that currents are virtually absent.

Ripple marks and mud cracks.—Ripple marks, like cross-bedding, are developed only in sands, not in fine muds, and their significance as

regards depth of water is entirely analogous. Both oscillation ripples and current ripples occur in Pennsylvanian formations, being most plentiful in sandy shales and shaly sandstones.

Mud cracks are found chiefly in the non-marine part of the Pennsylvanian, and are common in the Conemaugh and Monongahela, for example, in the Appalachian district. They denote exposure of the sediment to the air and are of interest especially where they occur closely associated with marine strata.

Current markings.—The under side of some thin sandstones in the Pennsylvanian of the Mid-Continent show a variety of straight and irregular raised markings that represent filling of depressions in the muddy sediments below.[1] These are very similar to markings in the Portage beds of New York, described by Clarke,[2] and they may likewise be interpreted as impressions in the soft, muddy bottom by drifting matter, by organisms, and possibly but doubtfully by shore ice. Whatever their origin, the markings seem to indicate extremely shallow water.

LATERAL PERSISTENCE OF BEDS

In the Appalachian, Arkansas, and southern Oklahoma districts, where the Pennsylvanian deposits are composed chiefly of clastic materials several thousands of feet in thickness, stratigraphic subdivisions of one area do not fit conditions in another; there are marked local irregularities. However, in the broad continental interior region of less rapid sedimentation, partly occupied by the sea and partly the site of lowland alluviation and of great fresh-water swamps, there is increasing evidence of remarkable lateral persistence of various stratigraphic units. Space permits reference to a very few of the many possible examples.

Among marine strata, the Fort Scott limestone, though only a few feet in thickness, is traceable nearly without change from its type locality in eastern Kansas southward well into Oklahoma and northeastward on the flanks of the Ozarks across Missouri into Iowa. It is recognized in the Pennsylvanian outlier near St. Louis, and is identified in the widely distributed limestone at the base of the McLeansboro formation

[1]Sidney Powers, "Strand Markings in the Pennsylvanian Sandstones of Osage County, Oklahoma," *Jour. Geol.*, Vol. 29 (1921), pp. 66-80.

[2]J. M. Clarke, "Strand and Undertow Markings of Upper Devonian Time as Indications of the Prevailing Climate," *New York State Mus. Bull. 196* (1917), pp. 199-238.

in Illinois, directly above the Herrin (No. 6) or Belleville coal.[1] This limestone extends into Indiana and Kentucky, and although not certainly identified, it is probably the same as one of the limestones in the upper Allegheny, or possibly the Brush Creek limestone near the base of the Conemaugh in Ohio, West Virginia, and Pennsylvania. The Fort Scott, commonly known as the "Oswego" by drillers, is one of the best subsurface markers in eastern and central Kansas and in northeastern Oklahoma. Evidently the epi-continental sea was at times not only extensive, but sub-uniform conditions prevailed.

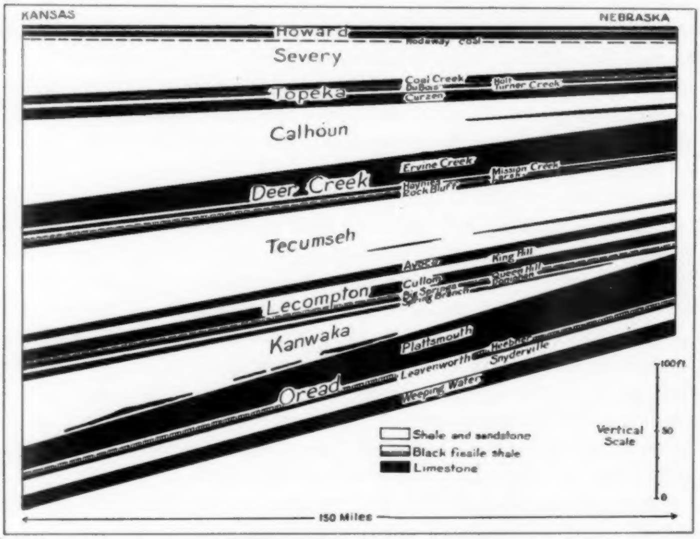

FIG. 2.—Diagrammatic section of a part of the Pennsylvanian from north-central Kansas to Nebraska, based on detailed field observations and measurements. The differentiation and nomenclature of the small stratigraphic divisions are those of Condra.

Rather widespread uniformity is even more strikingly shown by the persistence and the constancy of physical and faunal characters of other very thin stratigraphic units. The Leavenworth (Middle Oread) lime-

[1] J. B. Knight, "Some Pennsylvanian Ostracodes from the Henrietta Formation of Eastern Missouri," *Jour. Pal.*, Vol. 2 (1928), p. 229; "The Pennsylvanian Outlier of St. Louis, Missouri, and its Correlations," paper read before *Geol. Soc. Amer.* (New York, 1928).

stone, nowhere more than two feet thick, extends from Nebraska and Missouri entirely across Kansas. In the upper part of the Brownwood shale a thin, shaly limestone, bearing plentiful *Triticites irregularis* (Schellwien and Staff), extends across north Texas. Pennsylvanian sections measured in Nebraska, with subdivisions a few inches to a few feet thick, can be matched bed for bed in central Kansas. This is an amazing fact, not at all in harmony with the former prevalent view that the Pennsylvanian rocks are chiefly characterized by irregularity, and, of course, it is a very significant fact as regards conditions of sedimentation and the environment of life in these areas.

On the lands, also, there seem to have been at times very widespread similar conditions. This is perhaps best seen in the continuity of many of the coal beds, but it is also shown by some of the sandstone and shale deposits. The Pittsburgh coal at the base of the Monongahela extends uninterruptedly throughout tens of thousands of square miles in Pennsylvania, West Virginia, and Ohio. Some of the workable coals of Illinois, Kentucky, Indiana, and Missouri are as persistent, and it is even possible that Coal No. 11 of Kentucky was originally continuous through Indiana, Illinois, and Missouri with the coal at the Fort Scott horizon in Kansas and Oklahoma. Even the very thin Nyman coal, mostly less than three inches in thickness, is identifiable by reason of its stratigraphic position throughout thousands of square miles in contiguous parts of Iowa, Missouri, Nebraska, and Kansas.

INTERFINGERING OF CONTINENTAL AND MARINE DEPOSITS

In almost every part of the Pennsylvanian deposits of North America there are repeated alternations of continental and marine facies. Locally the succession may be entirely continental or entirely marine, and in places one or another type is dominant, but generally this system is noteworthy from the standpoint of fluctuating relations of land and sea. The Pennsylvanian is preëminently paralic. The very great advances and retreats of the sea can be traced definitely in many places, and from the lithologic characters, thickness, geographic extent, and number of interfingered facies of land and sea origin it is clear that relief of the entire depositional surface must have been extremely small, and accordingly that very slight changes in the relative position of the sea-level would result in pronounced shifts of the strand line. It follows, also, that the general surface of the accumulating sediments, marine and non-marine, must have been maintained very close to the critical position of sea-level.

If the inland sea were cut off from the open ocean, its level would be raised by sedimentary infilling, provided the quantity of water remained essentially constant; thus, irregularities in location and amount of deposition in the basin would cause local extension of land at the expense of the sea and would produce submergence in areas of less rapid sedimentation, and there would be additional oscillatory effects from minor warping and changes in water volume due to dominance of evaporation or precipitation. It is not at all improbable that such isolation of parts of the epi-continental sea occurred, but this was probably local and temporary rather than general and long persisting.

From time to time new genera or species of invertebrates that are known also in Eurasia or other foreign territory appeared in the waters of the North American interior, thus indicating connection with the open seas. If the inland seas were joined to the ocean throughout most or all of Pennsylvanian time, sea-level should remain relatively steady, and the deposition of many hundreds of feet of sediment that originally were slightly above or below the sea-level must have been accompanied by progressive sinking; thus, unevenness in rate of outward building of the land and of down-warping would produce pronounced fluctuations of the sea margin such as are observed. The latter set of conditions is probably more nearly the fact.

SIGNIFICANCE OF CHANGES IN LITHOLOGIC CHARACTER

Vertically and to a lesser degree horizontally, there are changes in the lithologic character of most Pennsylvanian deposits. Sandstone may grade into sandy shale, the sandy shale into clayey or limy shale, and this in turn into limestone, and at least in vertical succession the changes may be abrupt and exceedingly numerous. What are the conditions responsible for these repeated changes? They are not the result simply of more or less considerable shifting of the shore line, for they are too numerous and too persistent laterally. For example, in the northern Mid-Continent region there are seven members consisting of alternating limestone and shale in the Lecompton limestone which has a total thickness of approximately 40 feet. It may be stated that the limestones denote clear waters in which land detritus was temporarily lacking, and that the shales represent turbid waters in which the environment was unfavorable for lime-secreting organisms. But are these contrasting conditions the result of changes within the sea, such as shifting of currents, or do they indicate changes in supply of land waste, signifying some diastrophic or climatic change? The fact that lateral gradation

in the nature of the sediments appears eventually does not essentially alter these questions. The areal distribution and uniformity of the majority of the thin mud sheets scarcely suggests the work of marine currents, but they may be explained satisfactorily by the effectiveness in transportation of waves in shallow water. However, this does not account for the presence of the mud itself. Possible causes are: (1) re-working and lateral shifting of fine clastic sediments from areas of rapid and somewhat irregular deposition, as in the geosynclinal area of southern Oklahoma, to parts of the basin distant from the sources of detrital supply, or more local re-working and shifting in developing new profiles of equilibrium after local changes in sedimentation or warping of the sea bottom; various factors may govern and condition such transfer; (2) slight relative elevation of land, rejuvenating streams and increasing supply of terrigenous material to the sea; this might be responsible for some of the major changes in type of marine sedimentation but not the minor, and although there are numerous disconformities in the Pennsylvanian continental deposits, the most significant effects of diastrophism must be those of the lands that furnished the real source of the sediments; (3) climatic changes, such as periods of subnormal precipitation, when, because of reduction in capacity of streams, deposition would be restricted largely to the lands, alternating with periods of superordinary rainfall when the loads of sediment previously dropped on the plains would be shifted by the enlarged streams to the sea, these changes being complicated to a degree by the influence of a varying density of the vegetation cover; the climatic factor may control some of the minor sedimentary oscillations but probably not all of them.

RELATION OF SEDIMENTATION TO SOURCE OF SUPPLY

Increase (1) in the thickness of Pennsylvanian deposits, (2) in the coarseness of sediment, and (3) in the proportion of continental to marine deposition, is observed in passing from the Mississippi valley eastward or southeastward into the Appalachian district, and likewise from Nebraska and Kansas into southern Oklahoma and Arkansas or from north Texas eastward and northeastward. The direction of these increases designates the position of the land areas that supplied the great bulk of Pennsylvanian deposits. In the opposite directions there is diminished thickness accompanied by overlap; fine sediment, including much limestone, dominant; and marine strata generally greatly exceeding non-marine beds. These relations suggest that the unsubmerged territory north and west of the main body of Pennsylvanian epi-continental

waters was a featureless lowland that contributed very little to the accumulation of sediments within the basin.

MARINE NEAR-SHORE ENVIRONMENT

Normally, waves are an important eroding and transporting force at and near the shore line, the main conditioning factors of work accomplished being depth of water and effective fetch of storm waves. Conditions of essential equilibrium will be attained when the seaward slope of the bottom is such that wave erosion is practically *nil* and transportation energy is so reduced that only fine materials can be moved. A very broad wave-cut and wave-built platform with rather uniform bottom conditions is formed, but, as pointed out by Johnson,[1] the slow shift of materials into deeper water will permit the waves, while retaining the profile of equilibrium, to eat slowly but relentlessly into the land.

In the Pennsylvanian epi-continental seas depths were possibly, in fact probably, almost nowhere so much as 100 fathoms, and so excessive would be the distance of transportation required to dispose in deep water the waste eroded from shores and contributed by streams that such disposal may be doubted strongly. The impossibility of deep continental waters except by very considerable down-warping, is evident when to the considerations already advanced are added facts concerning the volume of the Pennsylvanian sediments. We are led to the conclusion that the depth of the interior seas was insufficient to permit development of such profiles of equilibrium as are observed on present continental borders, and that there was little or no erosion of shores.

Along a very low, plant-mantled coast, where neither wave erosion nor sediment-laden streams supplied land detritus, limestone deposition may occur almost to the shore line.

Relation of Structure to Environment

The idea has been advanced by not a few geologists that the present attitude of the Pennsylvanian strata in the Mid-Continent region, which is a monoclinal westward dip averaging approximately 25 feet per mile, represents essentially the original position of the beds as laid down by streams or in the sea. For example, Suess[2] writes:

> Texas thus exhibits, beneath a Cretaceous series dipping gently to the east or southeast, another and older series which is slightly inclined toward the west. The inclination, everywhere trifling, is original.

[1] D. W. Johnson, *Shore Processes and Shore-Line Development*, Wiley and Sons (New York, 1919), pp. 228-58.

[2] E. Suess, Sollas translation, *The Face of the Earth*, Vol. 4 (1909), p. 80.

If the validity of this concept be accepted, it follows that the sea in which the Canyon limestones of north Texas were deposited must have been 3,000 or 4,000 feet deeper in Haskell and Jones counties than in eastern Palo Pinto County, for there is this amount of difference in elevation of the limestones in these places due to westward dip. Further, inasmuch as erosion has removed an unknown thickness of beds on the east and inasmuch as the Canyon probably extends to greater depths in West Texas, this difference in depth of water, according to hypothesis, must have been greater than here indicated. The same considerations apply to other west-dipping Pennsylvanian strata.

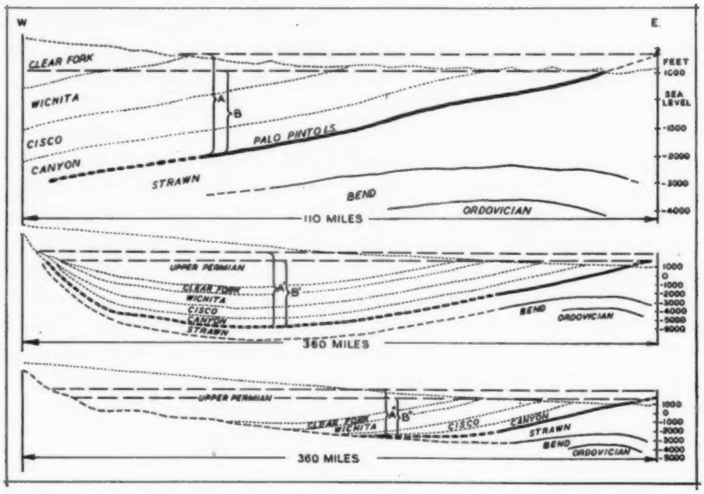

FIG. 3.—Diagrammatic sections of Pennsylvanian and Permian deposits of north-central Texas, with indication of depth of the sea, under the hypothesis that the strata were laid down in their present attitude.

Upper figure: Section from Palo Pinto County to Haskell County, based on numerous well records. *B* represents the difference in elevation (depth of sea) of the Palo Pinto limestone at its outcrop and in a deep well; *A* represents a greater difference (depth) between the original eastward elevation of the Palo Pinto limestone and elevation in a deep well. *Middle figure:* Hypothetical cross section from Palo Pinto County, Texas, to the west border of the Permo-Pennsylvanian basin in New Mexico. It is assumed that the stratigraphic divisions extend throughout the basin. *B'*, difference in elevation of Palo Pinto limestone (depth of sea) allowing for erosion at eastward margin; *A'*, a greater difference (depth) based on the highest elevation of marine strata in the basin. *Lower figure:* Hypothetical section, same as last, but assuming westward overlap of formations.

Because in Texas and other parts of the Mid-Continent region, continental deposits are very deeply interfingered with marine strata, it becomes necessary under the initial-dip hypothesis to assume innumerable up-and-down movements of the relative sea-level, and each of these

must have amounted to hundreds or even thousands of feet. Such violent instability should have been most disturbing to the contending forces of the sea and the land. Not only so, but to the extent that subaerial deposits reach farther down dip in some places than in others at a given horizon, there must have been very strongly *differential* upward and downward movements of the borders of the basin.

As shown by very many stratigraphic sections, constructed from surface and subsurface information, with aid of microscopic study of lithologic characters and fossils, (1) the lateral persistence of rock units of different kinds, some of which are almost certainly of very shallow-water type, (2) the approximate uniformity of thickness of stratigraphic divisions, and (3) the evidence of the fossils, all suggest that essentially similar environmental conditions must have existed throughout the area of sedimentation at time of deposition. It is now known in Kansas, Oklahoma, and Texas that several lower Pennsylvanian formations terminate westward at certain places, being overlapped by higher beds. This condition is inconceivable under the hypothesis that the strata now occur in their original attitude. Why should the west-dipping strata, in no sense comparable with deltaic foreset beds, come abruptly to an end, and how could the westerly parts of this supposed deep basin remain entirely devoid of sediment until late Pennsylvanian or Permian time? The answer seems to be that there is no valid evidence of the existence of such a basin. Rather, the seas may be conceived to have been always shallow. As sedimentation proceeded accompanied by slow, more or less uneven subsidence, and as continental materials crowded more and more westward, the sea invaded areas on the west side of the basin that earlier had received no deposits; hence, the overlap.

Summary

Evidence concerning the environment of Pennsylvanian life in North America consists of (1) very plentiful, commonly well-preserved fossils of marine and non-marine plants and animals, and (2) the lithologic character and stratigraphic interrelations of the containing rocks.

The known life of the lands is typical of a broad, moist, warm to subtropic lowland, on which, periodically, there were extensive swamps, shallow lakes, and marshes. Stratigraphic observations indicate that from New England southward along the general course of the Appalachians but east of them, and probably extending to East Texas, there stretched a land of unknown width and height the erosion of which supplied most of the detritus laid down on the piedmont and lowland areas

of the land and in the interior sea. The Pennsylvanian strata are thickest, coarsest, and most dominantly non-marine in the belt nearest the source of sediments, but this region was the site of coal swamps as well as of mud, sand, and gravel deposition by moderately swift-flowing streams. The remaining land was a vast swampy plain slowly built up and extended by stream alluviation, periodically more or less widely submerged to shallow depth by the sea.

In the sea, the faunas are characteristically those of shallow waters. Lithologic and structural characters of many of the beds denote slight depth of water, and interfingering of marine and non-marine sediments furnishes presumptive indication that the sedimentary surface was not very greatly depressed below or elevated above sea-level. There are some lateral variations in the Pennsylvanian marine deposits which are to be correlated with differences in environment, but most striking is the great lateral persistence of many of the thin stratigraphic units. Similar physical conditions must have prevailed in such areas of like sedimentation. The seas were not only very shallow but they were excessively fluctuating. The view that the strata of the Mid-Continent region were laid down in essentially their present position is untenable.

SESPE FORMATION, CALIFORNIA[1]

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ABSTRACT

A review of the available data shows that many features of the Sespe formation are in great need of further detailed study. So far as the desert hypothesis for the origin of the formation is concerned, the evidence at hand seems to be almost entirely unfavorable. It is certain that at least a part of the land areas were more thoroughly weathered than they were during later epochs which are known not to have been arid. This degree of weathering suggests warmth and humidity. The basin of deposition may have been less humid, and there is a suggestion that it may have had an alternation of wet and dry seasons. There is little justification, however, for the view that its climate was more than semiarid.

INTRODUCTION

The Sespe formation has been recognized and mapped in some detail by many geologists throughout a large area in Ventura and Santa Barbara counties, California. It is best known for its red, non-fossiliferous facies, which is conspicuously developed in the Santa Ynez Mountains between San Marcos Pass, near Santa Barbara, and Sespe Canyon, in central Ventura County. Like the red beds of other regions, this formation has given rise to much speculation. It is generally considered to mark an arid stage in the climatic history of the Tertiary period (4, p. 752; 6, p. 13; 9, p. 357; 10, p. 746).[3]

The purpose of the writer is to summarize the data now available concerning distribution, primary structures, and mineral composition of the formation; to put on record additional data of this kind, with particular reference to the character of the accessory minerals; and to present for consideration a new hypothesis as to the physiographic conditions under which the detrital materials of the formation were weathered.

THE DATA

All available information, old and new, as to the petrology of the

[1]Manuscript received by the editor, February 22, 1929.

[2]1717 South Third Street.

[3]The numbers in parentheses, with or without page references, refer to the bibliography at the end of the paper.

Sespe in eight widely scattered areas is summarized in the first section of the paper. Under each locality are given: (1) general lithologic data as to thickness and character of the beds exposed, and (2) petrographic data, including especially a description of the rock types represented among the pebbles, the essential and secondary minerals of the sandstone, and occasionally other features, such as the cement, that may have a bearing on the problem of the origin of the formation. In a following section the data for the several areas are assembled and compared, in an attempt to present a fair general description of the formation. Finally, the sedimentational problems are discussed. This procedure makes unavoidable a certain amount of repetition, but there seems to be no equally satisfactory way to review the voluminous but patchy information, and make clear the uniformity with which all of it points to the same conclusion.

The several areas from which samples have been chosen for special description are: (1) Sespe Creek, north of Fillmore (the type locality), (2) South Mountain and the adjacent area south of Santa Clara River, (3) Simi Valley (Moorpark and the country adjacent), (4) Ojai Valley and Red Mountain, near Ventura, (5) San Marcos Pass, near Santa Barbara, (6) Corral Canyon, 20 miles west of Santa Barbara, (7) the ridge north of Point Conception, and (8) Upper Santa Ynez River valley.

1. SESPE CREEK, THE TYPE LOCALITY

> The Sespe. . . .occupies a comparatively large area in the country drained by Sespe Creek. At the type section the Sespe consists of about 3,500 feet of strata. . . .Its most striking and characteristic feature is its dark reddish-brown color. The strata consist mainly of a massive medium-grained sandstone. Some parts are rather shaly, and conglomerate occurs at intervals through it . . . .The sandstone is well bedded. . . .Some of the thick beds of brownstone that are devoid of pebbles make very good building material (7, p. 31).

The bedding of the formation varies, but is in general regular. Thick sandstone beds (10 feet or more) are in many places separated from one another by a few inches of dark red shale or siltstone. Shale members may be several feet thick, with bands of siltstone interbedded. The conglomerate is commonly included in the sandstone strata, ordinarily at the top or bottom. In many places the matrix of a conglomerate bed grades without a break into the sandstone. Some sandstone beds also have lines or lenses of pebbles in them here and there. The bedding of the sandstone is defined not only by the interbedded shale bands and lines of pebbles, but also by alternations of finer and coarser sand. These may be parallel with the bedding or oblique (cross-bedding). Within a

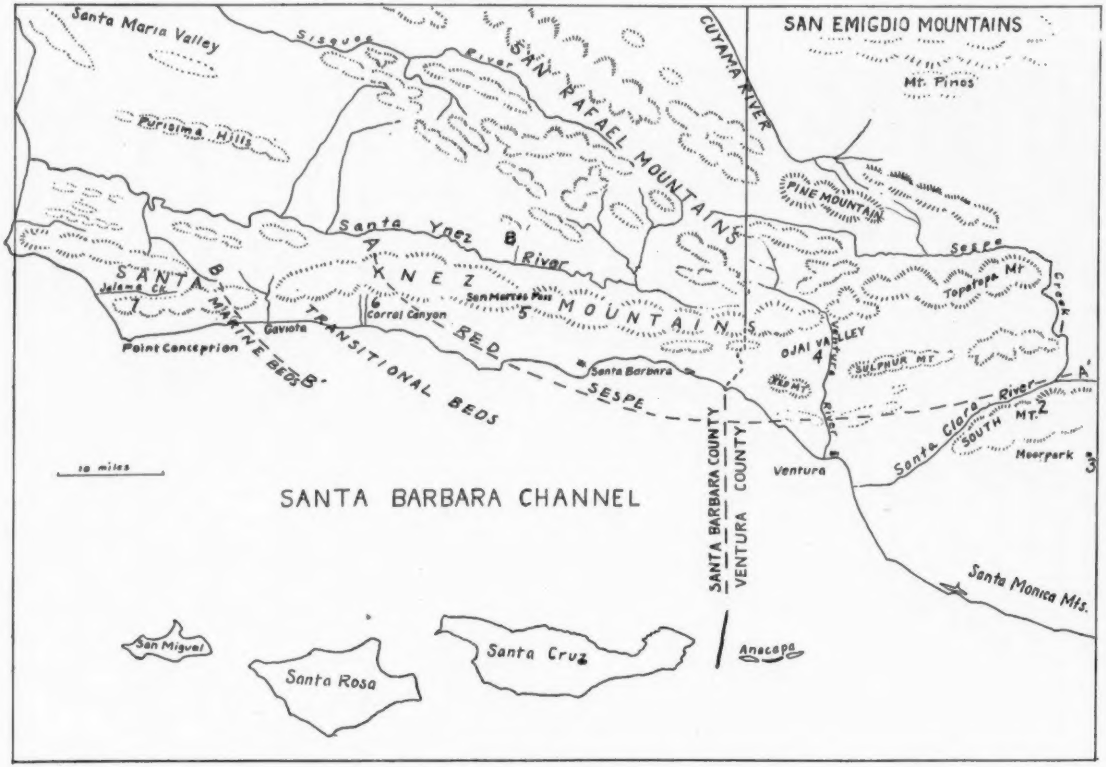

FIG. 1.—Santa Barbara district. Numbers refer to localities described in text. *A-A'* and *B-B'* show approximate boundaries separating marine, transitional, and red facies of the Sespe formation.

thick bed of sandstone there may even be evidence of channeling during deposition. In one place a fine sand had been slightly channeled, and the channels filled with a much coarser sand. The contact between the two, however, is not a plane of easy cleavage.

Almost the only petrographic information already published is contained in Eldridge's sentence (3, p. 7): "Throughout the formation the materials, whether fine or in the form of pebbles, are chiefly granitic." He added that the reddish color is due chiefly to iron, but also somewhat to pink feldspar. The dominance of granite among the pebbles is striking, especially if this locality is compared with others. Aside from granite and pegmatite, there are a few pebbles of quartzite, some chlorite and sericite schist, granitic gneiss, and fragments of dark reddish shale. Chert was not observed. The pebbles range in shape from angular to well rounded; most of them may be classed as fairly well rounded. The largest are approximately a foot in greatest dimension; the average is 2 or 3 inches. The plentiful sandy matrix in most of the conglomerate bands has already been noted.

The sandstone ranges in color from rusty gray to deep red ($1^{3+}i$—$1^{3}1$, on Goldman's color chart), the finer material being commonly most deeply colored. Mica is readily seen on a freshly broken surface. The quartz and feldspar grains are angular and are set closely together in a small amount of brown matrix. On many polished surfaces thin bands of irregular coarseness may be seen. Long feldspar grains may be arranged parallel with the bedding. A thin section shows that feldspar is somewhat more plentiful than quartz, and that much of it ranges from slightly to completely turbid because of weathering products. Few of the grains show any appreciable rounding. The pink feldspar mentioned by Eldridge is plentiful, but the color seems to be due chiefly to a ferruginous coating on the surface and along the cleavage planes of the grains. A curious feature noticed in the thin sections and on some polished surfaces is the occurrence of grains which appear clearly to indent other grains without shattering them.

The accessory minerals of the typical Sespe are opaque ores, zircon, epidote, titanite, garnet, and a few other very stable species. No amphiboles or pyroxenes have been recognized. Biotite is plentiful.

The cement of the sandstones is a red mud which differs in amount with the fineness of grain of the rock. It is very slightly calcareous in the samples tested. This cement is seemingly similar in character to the material composing the shale beds of the formation, but the latter have not been studied petrographically.

2. SOUTH MOUNTAIN AND ADJACENT AREA

Lithologic data are much more plentiful for the rocks of the South Mountain area than for those of Sespe Canyon. All observers have been impressed with the difference between the formations in these two localities, only 5 or 6 miles apart. A consideration of the great amount of north-south shortening that has been caused by later Tertiary deformation (7, Plate II, section *B-B'*) makes the phenomenon more intelligible.

Kew (7, p. 33) notes the presence of more than 5,000 feet of Sespe strata at South Mountain, and gives a section according to the field and subsurface studies of F. S. Hudson. It shows from 5,500 to 6,315 feet of varicolored shale and sandstone beds; some of the latter are described as conglomeratic and one as arkosic. Kew also mentions that near the top of the Sespe a little farther east there is a unique occurrence of "two limestone beds 1½ to 4 feet thick.... in the greenish clay."

A columnar section with lithologic description of the beds exposed on the north side of South Mountain is given by Reinhart (10, p. 744). The same writer gives graphic representations of the results obtained by screening grains from three samples collected in this area. One is a sandstone; a second, the matrix of a conglomerate; the third, a shale. He concludes:

> These analyses make it apparent that the sediments are terrestrial rather than marine in origin, for in marine deposits the assortment is much better than that here developed.

Since no analyses of marine sediments are given for comparison in support of this statement, it seems that the author relied upon the shape of his curves as proof of his conclusion. The varying ratios of mesh openings in the screens used, however, make the shapes of the curves a doubtful guide to the character of the sorting. The fact that all three curves have the same general shape is further evidence leading to this conclusion. If the data for his sample No. 1, furthermore, are transposed to a cumulative-percentage curve, the irregularities disappear, and the sand proves to be fairly well sorted. It is actually considerably better sorted than one of the marine Tejon sandstones analyzed by Woodford (11, p. 175, No. V). Instead of supporting his conclusions, therefore, Reinhart's data tend to confirm the judgment of earlier observers who have generally considered the Sespe sandstone to be "well sorted."

Several observers have noted the types of pebbles common in the strata of this area. Eldridge, for example, wrote (3, p. 10): "Both red

and gray beds are locally conglomeratic, the pebbles comprising clear quartz, red and blue quartzites, granite, chert, eruptives, and metamorphic rocks of several varieties." Kew notes that the "coarser material is derived from granitic rocks, though pieces of acidic volcanic rocks are not uncommon" (7, p. 33). Reinhart found, however, that the pebbles he collected were "composed mainly of chert with some quartz and rhyolite" (p. 744).

A coarse, friable, yellowish sandstone from Grimes Canyon showed angular grains in which quartz predominated greatly over feldspar. Another from Shiells Canyon contained more nearly equal amounts of the two minerals. There is great probability that the average quartz-feldspar ratio would be approximately 1:1 in this area as elsewhere throughout the formation.

A few samples have been examined for their heavy mineral content. One had epidote dominant, with opaque ores, titanite, garnet, and zircon all common. Green amphibole and apatite were very rare. A second sample had zircon dominant and the opaque ores only moderately plentiful. The other constituents were the same, except that amphibole seemed to be absent. A third sample had green hornblende fairly common. It is remarkable as being the only Sespe sample yet studied from any locality, in which any amphibole could be listed as even fairly common.

A few samples of light gray nodular limestone were collected from a bed near Shiells Canyon, and studied by means of polished surfaces and thin sections. The nodules are embedded in a greenish clay. They consist of fairly pure, fine-grained calcite, with many small cracks and irregular areas of coarser-grained calcite. The only traces of organisms are narrow curved lines somewhat more transparent than the matrix. In size and shape these resemble cross sections of ostracods.

Résumé.—The Sespe strata of the South Mountain district are much more diverse in color than those of the type locality, but are otherwise similar. The heavy minerals are dominantly of extremely stable types, such as might have been yielded by thoroughly weathered igneous rocks or by older sedimentary rocks. No minerals from the Franciscan schists have been observed.

3. SIMI VALLEY

Yellowish Sespe sandstone, with thin gravel beds and lenses, is exposed in a cut on the highway a short distance east of Moorpark. These beds are but a small part of the total thickness in this area, which is computed by Kew (7, p. 34) to be approximately 5,000 feet.

The pebbles collected from this outcrop range in shape from angular to well rounded, the most of them being perhaps best described as subangular. Many of them range from 1 inch to 2 inches in diameter, the largest possibly 6 inches. A small collection was determined as follows.

Volcanic pebbles, chiefly acid porphyry, no basalt	27
Gray gneiss	12
Quartzite, very well rounded	3
Jasper	3
Coarse-grained, light-colored granitic rock	2

A large crop of heavy minerals was extracted from a sample of yellowish friable sandstone from this area. Garnet, black opaque ores, zircon, apatite, pleochroic epidote, and titanite are commonest. There are very rare grains of green hornblende and rutile.

Résumé.—The few pebbles studied are chiefly from volcanic and metamorphic rocks. The heavy minerals are like those already described for other areas. The extreme rarity of hornblende and the absence of glaucophane are noteworthy.

4. OJAI VALLEY AND RED MOUNTAIN

The Sespe strata in and around Ojai Valley are similar in general appearance to those of the type locality. Fairly plentiful data concerning them are given by Eldridge, Cartwright (2, p. 241), and Gianella (4).

Cartwright has made the most elaborate studies so far reported of the pebbles in the Sespe of this area. He mentions the occurrence of granite, rhyolite porphyry, granodiorite, alaskite, syenite, basic porphyry, gneiss, mica schist, quartzite, serpentine, chert, organic limestone, sandstone, graywacke, greenstone, and glaucophane schist. A recent examination of some of the conglomerate beds shows much diversity from place to place. Some beds have chiefly veined jaspers and cherts; some have many fragments of red sandstone; others have very plentiful greenstones. Most of the rock types mentioned by Cartwright seem to occur but rarely.

In the sandstones, the quartz-feldspar ratio seems to have the ordinary range, with the average approximately 1:1. A sample from the Ojai Grade had mostly fresh feldspar, but the proportion was decidedly inferior to that of the quartz. Other samples are more arkosic, but the feldspar is less fresh. In one sample chalcedony was present to the extent of nearly 50 per cent. These observations are in accord with those of Cartwright, who found that

quartz and feldspar, the latter commonly weathered and almost as plentiful as quartz, form from 75 to 90 per cent of the grains. Chert is prominent, forming from 3 to 15 per cent of the grains.

The importance of chert is greater in the samples from this area than from any other yet studied. This condition is presumably to be correlated with the exceptionally large amount of chert gravel.

Cartwright has given some data on the nature of the accessory minerals:

The ferromagnesian minerals are relatively plentiful, particularly biotite. Muscovite, chlorite, epidote, pyroxene, titanite, garnet, magnetite, and grains of a dense green igneous rock are present in different proportions.

The "dense green igneous rock" mentioned in this passage is common at many horizons in the Sespe, as well as in the older Tejon and younger Vaqueros of Ventura and Santa Barbara counties. It has not yet been as much studied as it should be, but a few grains from different places have the optical properties of serpentine. All of it probably comes from the Franciscan complex.

The most elaborate published account of Sespe heavy minerals is by Gianella, whose samples came from the section exposed "about 3 miles east of Ojai, along the Ventura County highway on the grade between the Upper and Lower Ojai valleys." Gianella lists 21 species, of which 8 are considered characteristic or common. These are muscovite, epidote, lawsonite, garnet, zircon, cyanite, glaucophane, and topaz. This list contains several minerals that are not common or characteristic in other slides made from samples collected along the same road. Lawsonite, cyanite, glaucophane, and topaz are, in general, absent from Sespe sandstones, or at most extremely rare and local. Titanite and apatite, on the contrary, are almost everywhere present in Sespe material from any locality, including that from which Gianella's samples were collected. Of these, apatite may have been removed by the treatment to which he subjected his material, but titanite would not have been thus destroyed, and its absence is remarkable.

Glaucophane and lawsonite, as Gianella implies, are interesting in suggesting a derivation from the Franciscan group. Glaucophane, in particular, the recognition of which is comparatively simple and certain, is important in this respect. Its presence adds to the proof furnished by such materials as the serpentine and jasper pebbles mentioned by other observers that the land areas of Sespe time had Franciscan rocks exposed upon them. Gianella is in error, however, in supposing that the presence of a few grains of glaucophane or other schist mineral in a Coast

Range sedimentary rock is exceptional in any other respect. As will be discussed later, the rarity of glaucophane in all Sespe samples, and its complete absence in most, is the feature most difficult to explain.

Two samples collected from the chert conglomerate of the middle Sespe near Ojai contained interesting heavy mineral assemblages. One was from a fine-grained red sandstone interbedded with the conglomerate; the other was the matrix of the conglomerate itself. The common species are zircon, black opaque ores, epidote, titanite, and garnet, with such rare accessories as rutile. No amphiboles were detected in either assemblage.

Cartwright and Gianella give some data concerning the cement of the Sespe rocks of this area. The former found that "about 1/5 of the rock is matrix, composed of finely comminuted mineral matter, clay, and chalcedony." The latter states: "During the acid treatment the samples lost about a fourth in weight due to the solution of iron oxides and carbonates." The loss probably included mud, not actually dissolved, but washed away. These statements seem to show that the rocks of this area contain approximately 20-25 per cent of a material that may be called ferruginous mud.

Résumé.—The Ojai Valley Sespe differs from that already studied chiefly in the presence of more plentiful chert pebbles, and of a small proportion of minerals from the Franciscan schists. The cherts are so exceptionally plentiful as to suggest that a river draining some area of Franciscan rocks must have entered the Sespe depositional basin not far away. Under these circumstances, the great rarity of glaucophane seems to be without parallel in the California Tertiary section. Many accounts have been published of Miocene and Pliocene rocks in which the amphiboles, with glaucophane prominent among them, amount to 75 per cent or more of the heavy residue. That it should have been completely missed even in a few slides from the matrix of a chert conglomerate, and found present to the extent of "a few grains. . . . in each mount" in others from the same area, demonstrates the existence of some extraordinary condition on the land areas of Sespe time. Possible interpretations of the phenomenon will be discussed later.

5. SAN MARCOS PASS

The Sespe strata of the Ojai Valley district may be traced uninterruptedly westward to and beyond San Marcos Pass. Except where overturned, they dip steeply southward. The thickness (2,500 feet) is only about half that in the former region, but the general lithology is

very similar. Aside from a few beds of gray sandstone near the top of the section, the strata, which are beautifully exposed on the new highway across the range, are dominantly reddish in color. There is a sandy basal conglomerate more than 100 feet thick, which rests without angular discordance on oyster-bearing Eocene sandstone. The upper contact is likewise sharp, but not obviously unconformable.

Quartzite and other resistant rocks in small, well-rounded pebbles are conspicuous in the basal conglomerate. In another coarse member 400-500 feet above the base there are, in addition to such rocks as these, very numerous angular or rounded fragments of dark reddish shale. Sandstone beds throughout the section have many shale fragments, similar in all respects to the interbedded shale strata of the Sespe, in their basal parts and in places higher. Chert is probably present but was not observed.

A sandstone sample was collected for heavy mineral study from one of the gray beds in the upper part of the section. The lighter constituents were not studied. The heavy mineral residue is plentiful, and the grains appear clean. Zircon is probably the commonest species, and is ordinarily accompanied by apatite, garnet, titanite, epidote, and black opaque ores. Rutile and altered green hornblende are equally rare. Glaucophane is absent.

Résumé.—So far as the scant data show, the San Marcos Pass Sespe is mineralogically very similar to that occurring farther east. Both pebbles and heavy minerals are of stable types. There is the same striking scarcity of the ferromagnesian minerals that occur so plentifully in most later Tertiary sandstones in the Coast Ranges.

6. CORRAL CANYON

A few samples were collected from the upper part of the Sespe strata exposed in Corral Canyon, nearly 20 miles west of Santa Barbara. These beds are easily traceable into those at San Marcos Pass; they have the same steep south dip and are overlain and underlain by the same formations as the latter. They differ, however, in the much greater proportion of greenish-gray sandstone and greenish shale. Some red beds, especially shales, are found for 15 miles or more still farther west, nearly to the line beyond which the strata are demonstrably marine. The thickness of the formation, as measured a mile west of Corral Canyon, is 1,770 feet.

The only coarse materials observed in the small part of the section visited were fragments of green shale in the base of many sandstone

beds. These are similar to the red fragments mentioned as occurring in the San Marcos Pass sandstone. In Refugio Canyon there is a basal conglomerate similar in appearance to that at San Marcos Pass. It is probably present also in Corral Canyon.

The quartz-feldspar ratio in a sandstone sample from this area is approximately 1:3 or 1:4, the lowest observed in any sample. Half or more of the feldspar grains are turbid from weathering products. Aside from the presence of more apatite, the heavy mineral assemblage appears to be identical with that last mentioned. One weathered grain was doubtfully identified as amphibole.

Upon being washed in water, the friable sandstones give a moderate amount of greenish mud, the mineralogical nature of which has not been investigated.

Résumé.—The Sespe beds of the Corral Canyon section seem to be mineralogically identical with those farther east, except that the matrix of the sandstone is green instead of red mud.

7. RIDGE NORTH OF POINT CONCEPTION

On the ridge south of Jalama Creek and north of Point Conception there is exposed a series of light gray to yellowish sandstone and dark gray clay shale. From these beds a few marine mollusks have been collected, which are reported to be of Oligocene age. It was not supposed that these strata could be correlated with the Sespe formation, but detailed mapping demonstrated the equivalence. The continuity of the formation and its striking lateral variations may be most readily observed by flying at an altitude of 5,000 or 6,000 feet along the crest of the Santa Ynez Range in such a position as to look southward directly down the dip of the strata. The formation then appears as a nearly straight band which gradually changes from dominantly reddish to gray, and from dominantly brush-covered (sandy) to grass-covered (shaly).

No coarse materials have been studied in the Point Conception strata. The sandstone is notably micaceous; some beds contain many fragments of carbonized wood. Rare marine fossils occur in others. The light minerals have not been studied. A slide of the accessory minerals shows opaque ores, apatite, and zircon, as the plentiful constituents. Epidote, titanite, tourmaline, and rutile are noticeable, and one platy yellow grain is probably brookite. No amphiboles are present.

Both arenaceous and calcareous *Foraminifera* are plentiful in the shale. Its mineral constituents were not examined.

Résumé.—In relative content of shale, and in the presence of organisms, the marine Oligocene differs from the Sespe beds farther east. In mineral composition it does not differ from them.

8. UPPER SANTA YNEZ RIVER VALLEY

The Sespe strata north of the Santa Ynez Range are not continuous with those south of it. That they are correlative with the latter, however, there are many and varied proofs, which need not be summarized here. The strata of this area occur in several patches, one north, the others south of Santa Ynez River. The former, the farthest north of any that has been described in published form, is discussed as follows by Nelson (9, p. 356):

> The Sespe is much thinner north of the river than south of it. On the eastern side of Loma Alta the sediments total 230 feet..... The.... section consists of sandy, maroon-colored shales which grade into soft, concretionary, fine-grained sage-green sandstones. Greenish to brown-colored conglomerates, interbedded with lenses of reddish sandstones, are exposed east of Oso Cañon. The conglomerate is made up of unsorted Franciscan pebbles, up to 5 inches in diameter, in a sandstone matrix.

The exposures south of Santa Ynez River have been described by Kew (6, p. 12). He states that the section is 1,700 feet thick, and that it consists of fanglomerates, cross-bedded sandstones, and minor amounts of shale and limestone. The coarser constituents are reported to consist dominantly of Franciscan fragments, some of them as much as 14 inches in diameter, in a matrix of greenish material. "The sandstones are well sorted, clean and show well developed cross-bedding. The colors are also highly variegated....." Near the top are a few thin layers of impure limestone.

In summary, the Sespe strata north of the Santa Ynez Mountains seem to belong to the marginal facies of the formation. Petrographically they are almost unknown, but are similar, in all respects about which there is information, to those already described. Their chief interest in the present connection lies in their thinness and in their probable proximity—as shown by the number and especially by the large size of their Franciscan fragments—to an old land mass of Sespe time.

SUMMARY OF DATA

The Sespe formation is predominantly sandstone and sandy shale, with locally important amounts of conglomerate, and rare and local beds of limestone. In its typical development the formation is reddish

or deep brown in color. South and southwest of the areas of reddish material, are gray, yellowish, and greenish non-marine strata, and these grade into a marine formation with Oligocene mollusks and a good foraminiferal fauna. These relations are sufficiently well shown on the sketch map (Fig. 1).

The bedding of the Sespe seems not to have been very carefully studied. Some parts of the formation have been described as characterized by lenticular beds. Nobody has demonstrated for any part of it, however, the occurrence of irregularities more striking than those common in marine formations in the same district. One observer, at least, has always been impressed with the regularity of bedding of the Sespe. The formation is far from being an aggregation of mud flows, or even of fanglomerates. The uniformity of bedding and sorting implies the presence of water currents of tremendous power and efficiency. If the Sespe basin is thought of as deltaic, it is clear that the delta must have been that of a very large river. There is little resemblance between the strata and those of an alluvial fan built in an arid region by occasional floods.

A characteristic feature of the Sespe, as of many other Coast Range formations, is the occurrence of numerous shale chips in the base of many sandstone strata. The phenomenon shows that the clay beds were hard before the deposition of the overlying sandstone. Exactly similar conditions are found commonly in the Cretaceous rocks, in the Miocene—even in alternating diatomite and sandstone in the Temblor Range—and in the Pliocene. Whatever the conditions that were necessary for the phenomenon, therefore, they were not peculiar to the Sespe.

Fifteen years ago Lawson proposed the term "fanglomerate" for the coarse phases of continental deposits of alluvial fan type. The conditions necessary for its development are given as "bold relief and aridity" (8, p. 332). Lawson noted the extreme scarcity of known fanglomerate among the rocks of the past at the time he wrote. This scarcity no longer exists. Later observers have applied the term to many unfossiliferous coarse formations, always with the implication that the formations so designated are alluvial fan deposits of semiarid mountain regions. The implication may be correct, but its importance demands that the criteria for distinguishing fanglomerates from other coarse and poorly sorted rocks be most carefully applied. This necessity is all the more evident from the fact that Blackwelder now believes many typical fanglomerates to be of mud-flow origin (1, p. 366).

Most of the Sespe conglomerates are plainly not mud flows, or different in any perceptible way from marine and non-marine conglomerates in other formations of the same general region. This statement is true for all localities described in the present paper, except the Santa Ynez Valley region. Here Kew and Nelson have noted the presence of fanglomerates. This occurrence is in the marginal part of the Sespe formation, adjacent to a part of the land area characterized by Franciscan rocks. These, as is well known, are peculiarly subject to earth flows and landslides in all modern regions where they occur, no matter what the climatic conditions are. The Sespe fanglomerate may, therefore, be taken as a good indication of bold relief, but not necessarily of any notable degree of aridity.

Few quantitative studies have been made of the sorting of Sespe sediments. Those of Reinhart, when re-calculated, show that the sandstone is better sorted than at least one marine Eocene sandstone. An analysis of a sample of friable sandstone made in the course of the present study corroborates this conclusion.

The pebbles of the formation range in shape from well rounded to subangular. The spherical quartzite and hard volcanic pebbles may be derived from older conglomerates. The other pebbles doubtless come from different distances. Nearly all of them can be duplicated in possible parent rocks not more than a few tens of miles from their present location.

In the type locality the pebbles of the Sespe are chiefly granitic. Jasper pebbles are most plentiful in Ojai Valley. In Simi Valley different types of volcanic rocks constitute the greater part of the conglomerate layers. Limestone is fairly common in Ojai Valley and possibly elsewhere. Quartzite, gneiss, and mica schist occur in small quantity almost everywhere. In the San Marcos Pass exposures, where conglomerate is not very plentiful, quartzite is a relatively prominent constituent. Fragments of hardened Sespe clays and of reddish sandstone occur rather commonly throughout the formation.

The sandstone grains, like all those of earlier and later Tertiary formations in the Coast Ranges, are angular to subangular. The angularity has been interpreted as indicating different exceptional conditions, but these attempts at interpretation fail to take account of the essential similarity of the Sespe fragments to those of other Coast Range formations.

The quartz-feldspar ratio differs considerably in different samples. Most of the feldspar grains show weathering, some to a slight, others to a high degree. In all this there is nothing to differentiate the Sespe

from other Coast Range formations such as the underlying Eocene and the overlying Miocene.

Chert grains are plentiful in the sandstone samples from Ojai Valley, the site of the great chert conglomerates. They are rare or absent from samples collected in other localities.

The rare accessory minerals, with a few exceptions, are extremely stable. Green amphibole, which is plentiful in many Pliocene beds, is a rare and local constituent in the Sespe. Pyroxene has been reported, but it has not been found during the present investigation. It must be very rare. Glaucophane has been found only as a rare constituent of some of the samples collected in the Ojai region. Its absence from others, especially from the matrix of a conglomerate containing very many Franciscan pebbles, is a most exceptional condition.

The cement of the red Sespe appears to be a highly-oxidized ferruginous mud. This feature of the strata has probably had much to do with the adoption of the aridity hypothesis for the origin of the formation. Nelson writes, for example (p. 357): "The oxidized character of the sediments suggests arid conditions during their accumulation." Alternative hypotheses are discussed later.

The shale members of the Sespe have been little studied. Many samples show scattered quartz and biotite grains large enough to be seen with the unaided eye. Some of them recall playa clays. Others more closely resemble ordinary lake clays and silts, or flood-plain muds.

The few thin, nodular limestone beds, with no organisms except rare ostracodes(?), probably accumulated in swampy areas or temporary lakes on the Sespe delta. What they mean with reference to climatic or other conditions is not clear. They recall descriptions of kunkar, the development of which requires "that periods of desiccation should alternate with periods of saturation" (5, p. 337).

The organic constituents of the nonmarine Sespe are petrographically unimportant because of their extremely small quantity. Their importance for correlation, however, and for ecologic speculations, is very great. The reports of further studies in this field may go far toward answering some of the questions that are obscure at present.

PALEOGEOGRAPHIC DISCUSSION

Some of the data here assembled give information concerning the character of the land areas of Sespe time (the "distributive province" of Milner and other writers), and others tell something about conditions in the area of accumulation. The problems concerning the two provinces intergrade, but may best be discussed separately.

Problems of the higher land areas.—The land areas of Sespe time were able to furnish a vast quantity of detritus, the greater part of which seems to be of granitic derivation. Conditions in the Ojai Valley suggest that somewhere not far away there was an area of Franciscan materials. It was probably the San Rafael Mountain area. Other rocks represented on the land were sedimentary, furnishing material such as rounded quartzite pebbles and angular sandstone fragments; volcanic (unless the volcanic pebbles are also re-worked); and metamorphic, furnishing gneisses and schists, with some coarsely-crystalline limestone.

The size of the land area that was drained to the Sespe lowland and sea must have been considerable. The character of the sorting and bedding of the sandstone suggests large rivers, which would probably not be present on a small land. The quantity of Sespe rocks now exposed or known to be buried, furthermore, amounts at least to several hundred cubic miles. These facts suggest a large distributive province, part of which may have been high, and all of which probably was rising so as to furnish continuously great quantities of dominantly coarse material.

The location of the land area must have been north and east of the red Sespe outcrops, inasmuch as the sea is known to have been on the southwest and west. A part of the present San Rafael Range seems to have been land, and so probably were some of the other ranges near it; and very possibly a large part of the present Mohave Desert was drained to the Sespe basin.

If the land was large and the relief considerable, the climate may well have differed much in different places. That it was arid is, as previously noted, a common belief among those who have studied the formation. Among the many reasons that have been given for this belief, two seem worthy of some discussion here. These are the character of the heavy minerals, and that of the cement.

The character of the heavy minerals is the feature in which the Sespe formation differs most strikingly from many later formations. In earlier studies of the subject it has been assumed that the difference was due solely to difference of source, and the presence of Franciscan schist minerals was considered "climatically unimportant." Further investigation demonstrates that the source was the same in Sespe time as later, however, and that Franciscan rocks, including glaucophane schists (9, p. 338), were well exposed on a part of the Sespe land areas. The same thing is true of the Eocene rocks in Santa Barbara County; they contain plentiful chert pebbles and few or no glaucophane grains

Eocene floras demonstrate that the lands were warm and humid, thus explaining a high degree of weathering of the exposed rocks. The Sespe land areas must have been similarly weathered—and the Vaqueros as well—a conclusion very difficult to harmonize with the usual beliefs about Sespe climate.

A thorough discussion of the climatic significance of red color in sediments is of course out of the question in this paper. The literature devoted to the problem is voluminous, and the difference of opinion among competent students immense. Both conditions indicate presumably that the problem is at present indeterminate, and that each occurrence of red beds should be studied without prejudice for its contribution toward an ultimate solution of the problem.

Concerning the red color of the Sespe rocks, one might hold: (1) that the color was developed on the land areas under (*a*) humid conditions, or (*b*) arid conditions; or (2) that the color was developed after deposition and burial of the sediments.

The distribution of the color, the occurrence of red shale chips in the basal part of many sandstone beds, and the absence of redness from Tejon and Vaqueros strata that are lithologically inseparable from the Sespe and have undergone the same post-depositional treatment, seem to be consistent with the idea of primary, rather than secondary, redness. If this conclusion be granted, there remains to be considered the question of climate on the land areas.

Red soils are now accumulating, as many geologists and soil specialists have shown, only in areas with a warm, humid climate, like that of the southern Appalachian Mountains. Inasmuch as the mineralogy of the Sespe formation suggests exactly the same conditions for Sespe time, is it not as justifiable to consider the red color of the formation an indication of warm, humid lands, as the reverse?

That the other features of the formation, such as angularity of grain and feldspar content, are not inconsistent with this conclusion may be sufficiently evident from the discussion on previous pages.

Problems of the basin of accumulation.—Field work shows conclusively that the red Sespe beds accumulated in a subsiding basin that was adjacent to, and northeast of, a shallow sea. The development of strong east-west folding and faulting in late Tertiary time makes difficult a reconstruction of conditions during the Oligocene. It is probable, as shown by Kew (6, p. 21), that the earlier folding occurred along northwest-southeast lines—the normal condition in the Coast Ranges.

The basin of typical Sespe strata was probably not continuously under water, but was watered by streams of large size. Wide areas of

mud flat occasionally became sufficiently dry so that renewed floods were able to break out fragments of hardened clay and embed them in their deposits of sand and gravel. The vegetation of the Sespe lands is completely unknown, and the vertebrates are still being studied.

Nearly all the data needed to interpret the climatic conditions of the basin of accumulation, such as the structural and textural features of the rocks, and especially the organic remains, are in need of further study. A few features, such as the appearance of some of the clay beds, and possibly the limestone, suggest that the basin may have been more arid than the higher lands. Its location immediately east of an open sea, however, and the absence of any typical desert features, do not suggest a pronounced degree of aridity.

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GEOLOGIC AGE OF THE MODELO FORMATION, CALIFORNIA[1]

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ABSTRACT

Direct evidence of the geologic age of the rocks constituting the type section of the Modelo formation in Ventura County, California, has never been recorded in the literature. The type section of this formation exposed between Sespe Creek and Piru Creek, along a line through Oat Mountain and the head of Modelo Canyon, consists of a series of sandstones, silty shales, siliceous shales, and cherts. This series of rocks has been described as resting conformably upon a formation containing a Vaqueros (lower Miocene) fauna, and as being overlain conformably by rocks characterized by fossils of Pico (lower Pliocene) age. As no unconformities have been found within the type section, it has been assumed by most of the geologists who have studied these rocks that the Modelo formation is a continuous series representing deposition during all of Miocene time subsequent to the Vaqueros period.

Fossils indicative of Temblor (middle Miocene) age have recently been found at two localities in the lower Modelo sandstone of the type section. A fauna indicative of uppermost Miocene (upper San Pablo) age has been found in a sandstone bed in the upper shale member of the type section of the Modelo. This sandstone rests with seeming conformity upon the underlying beds. At other localities, north of the type section, rocks formerly believed to be of Pico age, but which are now known to carry fossils indicative of uppermost Miocene age, rest with marked unconformity upon the underlying Modelo strata. The assumption of previous workers that the type section of the Modelo formation represents continuous deposition from post-Vaqueros time to the close of the Miocene is, therefore, amply supported by structural and paleontological evidence. At other localities a diastrophic break is evident at the base of the uppermost Miocene.

Our conclusion is that the Modelo formation of the type section consists of three divisions, which have the rank of formations. The lower division is of Temblor (Topanga, middle Miocene) age; the upper division is of uppermost Miocene (upper San Pablo, uppermost Miocene) age, whereas the middle division, which has not yet yielded fossils, is believed to be of lower San Pablo (Briones, lower part of upper Miocene) age.

INTRODUCTION

This paper contains some of the results of a geological survey of the Santa Clara Valley region, carried on during parts of 1927 and 1928 by geologists of the Shell Company of California. This work was under the direction of the senior writer, the other members of the field party being H. J. Buddenhagen, F. B. Carter, E. K. Craig, M. L. Hill, W. W. Rand, and G. H. White.

[1]Manuscript received by the editor, February 25, 1929. Published by permission of G. Legh-Jones, president of the Shell Oil Company.

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One of the important results of this survey was the discovery of fossils in rocks of the type section of the Modelo formation. These fossils were found by the writers, but no small amount of credit is due to the other members of the field party for their contributions to our understanding of this rather complex region.

GENERAL STATEMENT OF THE MODELO PROBLEM

Geologists have described a considerable number of formations and faunal zones as parts of the Miocene of California. The names of those divisions which have been used in more than a strictly local sense include Vaqueros, Temblor, Topanga, Monterey, Salinas, Maricopa, Modelo, Puente, San Pablo, and Santa Margarita. Distinctive macrofaunas are known from the Vaqueros, Temblor, Topanga, San Pablo, and Santa Margarita formations. Megascopic fossils which have been found heretofore in the other formations mentioned have proved of no value for correlation.

The term Modelo formation was proposed by Eldridge and Arnold[1] for that part of the sequence of Miocene strata in the Santa Clara Valley region, which lies above strata which they believed to be of Vaqueros (lower Miocene) age. The exposures of the post-Vaqueros Miocene in the mountainous region north of Santa Clara Valley, between Sespe and Piru creeks, were evidently considered by these authors to constitute the type section of the Modelo formation. They describe this section as composed of two prominent bodies of sandstone and two of shale, the lower sandstone resting "directly and apparently conformably upon the Vaqueros shale."[2] No fossils were found by Eldridge and Arnold in the rocks of the type section, but they report finding a form closely resembling *Pecten pedroanus* Trask in shales exposed south of the Santa Clara Valley, believed to be equivalent in age to certain beds of the type section, and they state that the type locality of *Pecten peckhami* Gabb is probably within the shales mapped as Modelo exposed on the south side of the Ojai Valley. They state that the shale of the Modelo formation "at many points bears a marked resemblance to that of the Monterey (middle Miocene), both from a lithologic and a paleontologic standpoint and it may be that it is the correlative of that formation.[3]

[1] G. H. Eldridge and R. Arnold, "The Santa Clara Valley, Puente Hills and Los Angeles Oil Districts, Southern California," *U. S. Geol. Survey Bull. 309* (1907), p. 17 *et seq.*

[2] *Ibid.*, p. 18.

[3] *Ibid.*, p. 18.

Kew[1] extended the use of the term "Modelo formation" to areas a considerable distance south and east of the area described by Eldridge and Arnold. In the region of the type locality he extended the formation downward to include a part of the shale which had been mapped by the earlier authors as Vaqueros.

He reports the discovery of an unconformity within the Miocene sequence of strata in the region north of the San Fernando Valley, and in the Santa Monica Mountains south of that valley. The strata beneath this unconformity carry a distinctive fauna of Topanga (Temblor = middle Miocene) age, whereas the beds above the unconformity contain, according to Kew,[2] "a meager fauna characterized by *Pecten raymondi* Clark, an upper Miocene species not recognized in strata older than the San Pablo formation (upper Miocene) of the San Francisco Bay region." These beds, yielding an upper Miocene fauna, are considered by Kew to represent the Modelo formation. With reference to the Modelo of the type locality, he states[3]

> the apparent conformity of the Vaqueros and Modelo here and on Oak Ridge presents a peculiar situation inasmuch as everywhere south of Oak Ridge the Topanga formation (Middle Miocene) intervenes between them. Two explanations for this anomaly can be advanced. The Modelo formation in the Santa Clara area may include the Topanga formation, the sandstones of which may be represented by shales in the basal part of the Modelo formation; or, on the other hand, the Topanga formation may never have been deposited in that area, the Modelo shales having been laid down by a transgressing sea. The latter explanation seems the more plausible, and it is thought that an unconformity will at some time be located.

Recent work by the writers at the type locality of the Modelo formation has yielded rather convincing evidence on the question of the age of this formation. As shown in the more detailed statements which follow, the first of Kew's alternative explanations is probably correct, that is, that the Modelo of the type locality includes strata of Topanga age, as well as beds representing upper Miocene deposition.

DESCRIPTION OF MIOCENE FORMATIONS, INCLUDING THE TYPE SECTION OF THE MODELO FORMATION

The Miocene strata exposed in the mountainous region north of Santa Clara Valley, between Sespe and Piru creeks, consist of an alter-

[1] W. S. W. Kew, "Geology and Oil Resources of a Part of Los Angeles and Ventura Counties," *U. S. Geol. Survey Bull.* 753 (1924), p. 55 *et seq.*

[2] *Ibid.*, p. 66.

[3] *Ibid.*, p. 58.

nation of bodies of sandstones and shales, with some conglomerates in the uppermost members. The lithologic character of these rocks, as seen along a line of section extending from Sespe Creek through Oat Mountain and Hutton Peak to a point on the east wall of Piru Creek Canyon, a short distance north of Holser Canyon, is described in the following paragraphs.

VAQUEROS FORMATION

Overlying the characteristic maroon sandstone and siltstone of the Sespe formation at a gradational contact, occurs a prominent ridge-forming, pale greenish-gray sandstone. *Turritella ineziana* and other Vaqueros fossils occur plentifully in calcareous siltstone interbedded with the sandstone. The gray sandstone grades upward within a few hundred feet to a greenish-gray siltstone stained on the fracture surfaces by hematite. Thin beds of nodular limestone, rich in fossils of Vaqueros age, are intercalated with the siltstone.

Previous workers in this region have placed the top of the Vaqueros at the base of a 40-foot, yellow-weathering, fine-grained, calcareous sandstone, occurring approximately 500 feet stratigraphically above the top of the Sespe. Although no megascopic fossils have been found above this sandstone, the siltstones both above and below are lithologically similar, and the sandstone inself grades laterally into a thick stratum of fine-grained, blue-gray, argillaceous sandstone, losing its distinctive character as a marker bed.

The writers prefer to consider the top of the Vaqueros to be at the base of a 100-foot series of heavy-bedded, yellow-weathering, siliceous limestone. The limestone beds can be readily traced from the Agua Blanca basin, on the Tejon quadrangle, to the alluvium near Fillmore. Although no local angular or erosional unconformity can be detected, the limestone series converges upon the basal Vaqueros sandstone from a maximum interval of 3,000 feet in the north to 1,100 feet at a point 7 miles south along the contact.

MODELO GROUP

The Modelo formation consists of a lower bituminous shale series, a massive lower sandstone, a middle siliceous-calcareous shale, an upper sandstone, and an upper cherty shale.

Lower shale.—This consists of hard, laminated, white-weathering, bituminous shale, overlying the basal limestones with gradational contact. It yields *Pecten peckhami*, and an abundance of *Foraminifera* and fish scales.

Lower sandstone.[1]—The dark bituminous shale grades upward through a thickness of 700 feet into a massive-bedded, buff, arkose, concretionary sandstone, with a few beds of grit. The lower sandstone attains a maximum thickness of nearly 3,000 feet in the upper end of Hopper Canyon. Toward the southwest the sandstone grades laterally into calcareous shale and limestone, the lower layers of sandstone extending much farther southward than the upper layers. In the steep slopes immediately north of Fillmore, the lower sandstone is represented by only a few thin lenses in a series of calcareous shales and siliceous limestones.

Middle shale.—Separating the upper from the lower sandstone is found a series of chocolate-brown shales with subordinate sandstone, limestone, and chert. This incompetent shale member is severely distorted in many places, due to its position between the two resistant sandstone bodies. The thickness ranges from 1,000 feet, in the apex of one sharply folded anticline, to 300 feet in the flank of the same structure.

Upper sandstone.—The upper sandstone is lithologically similar to the lower. The thickness varies rapidly by lateral gradation into calcareous shale from a maximum of 2,000 feet to a minimum of 500 feet.

Upper shale.—The upper shale is dominantly siliceous, with prominently outcropping reefs of siliceous limestone. Thin, irregular lenses of dark brown chert occur throughout a thickness of 700 feet.

The siliceous, cherty shale grades upward, with decreasing siliceous limestone, into massive, chocolate-brown, spheroidal-weathering siltstone, stained yellow with jarosite. The siltstone is rich in organic material, commonly foraminiferal, and weathers readily into gentle topography. The total original thickness of this terrigenous shale is not determinable, as the upper part of the formation has been eroded from the synclinal basin in which it occurs, but the total thickness is known to exceed 400 feet. No megascopic fossils have been found.

Stratigraphic break within "Upper Modelo shale."—The section of the "Upper Modelo shale" described in the preceding paragraphs culminates in the center of the synclinal basin west of Hutton Peak. The "Middle Modelo sandstone" which underlies the "upper shale" of this basin may be traced continuously eastward to Piru Creek. Between the top of the "middle sandstone" of the Piru Creek region and the base

[1]The base of this member was considered by Eldridge and Arnold to mark the contact between Modelo and Vaqueros, but, for previously stated reasons, the writers prefer to place the top of the Vaqueros lower in the section.

of the Pico (lower Pliocene) formation, is a series of strata which have heretofore been considered as "Upper Modelo shale." This series includes shale, chert, and thin-bedded sandstone below, and conglomerate, sandstone, siltstone, and minor amounts of siliceous shales above. The discovery of upper San Pablo (uppermost Miocene) fossils in the sandstone, approximately midway between the base of this conglomerate and the base of the overlying Pico, suggests that the lithologic break at the base of the conglomerate may well be considered the base of an upper San Pablo formation.

FOSSILS FROM LOWER MODELO SANDSTONE

The writers have recently found determinable fossils at two localities in the lower Modelo sandstone. These localities are north of Hopper Mountain on the high ridge which separates the drainages of Sespe Creek and Hopper Creek. These fossils were studied by A. J. Tieje. His determinations are here given.

Lot A.—From rather thickly-bedded, coarse-grained, somewhat calcareous, arkose sandstone, 1,300 feet north and 850 feet east from southwest corner of Sec. 22, T. 5 N., R. 19 W., S. B. B. & M.

- *Pelecypoda*
  - *Pecten andersoni* Arnold
  - *Pecten andersoni barkerianus* Arnold
  - *Pecten* cf. *crassicardo* Conrad
- *Gastropoda*
  - *Calyptraea filosa* Gabb
- *Echinoidea*
  - *Scutella* cf. *merriami* Anderson

Lot B.—From sandstone similar to that yielding Lot *A*, 1,000 feet north and 1,250 feet east from southwest corner of Sec. 22, same township as above.

- *Pelecypoda*
  - *Ostrea* sp.
  - *Pecten* n. sp.?
  - *Pecten andersoni* Arnold
- *Gastropoda*
  - *Calyptraea* cf. *costellata* Conrad
- *Echinoidea*
  - *Scutella* cf. *merriami* Anderson

Geologic age of lower Modelo sandstone.—The fauna of Lots *A* and *B* seems to be of Temblor (Topanga = middle Miocene) age. The two definitely determined species, *Pecten andersoni* and *P. andersoni barkerianus*, are not known to occur in strata of age other than Temblor or Topanga. *Pecten crassicardo* is generally regarded as an upper Miocene

form, but a new variety of *P. crassicardo* is recorded by Kew[1] in his list of fossils from the type locality of the Topanga formation. It is reported that both species of *Calyptraea* range from Temblor to Pico (lower Pliocene). *Scutella merriami*, doubtfully determined in both these lots, is reported to be restricted to rocks of Temblor age.

FOSSILS FROM UPPERMOST MODELO STRATA

A fossil locality in strata near the top of the type section of the Modelo formation was discovered in 1927 by the junior writer. One of the forms from this locality was determined by the writers as *Pecten pabloensis* Conrad, a determination with which A. J. Tieje concurred when the specimen was submitted to him. Later a considerable amount of fossil material was obtained from this locality and given to Dr. Tieje for study. His results are here given.

Lot C.—From a bed of cemented, pebbly, coarse arkose sandstone, enclosed in thinly-bedded, fine-grained sandstone, 4,100 feet north and 800 feet west from intersection of east boundary of Temescal Rancho with east boundary of Piru quadrangle.

Pelecypoda
- *Glycimeris* sp.
- *Leda* sp.
- *Ostrea titan* Conrad
- *Ostrea* cf. *bourgeoissii* Remond
- *Pecten pabloensis* Conrad

Gastropoda
- *Calyptraea filosa* Gabb
- *Cerithium* cf. *rodeoensis* Clark
- *Olivella* sp.
- *Trophosycon nodiferum* Gabb

Geologic age of horizon of fossil Lot C.—The fauna represented by Lot *C* seems to be definitely of upper San Pablo (uppermost Miocene) age. According to Arnold[2]

> *Pecten pabloensis* is so far known only in the San Pablo, or Upper Miocene formation. At the type locality, on the shore of San Pablo Bay, Contra Costa County, a bed several feet thick is made up almost entirely of valves of this species.

The work of Clark[3] in the region of the type locality of this form, indicates that *P. pabloensis* is restricted to the uppermost division of

[1] *Op. cit.*, p. 51.

[2] R. Arnold, "Tertiary and Quaternary Pectens of California," *U. S. Geol. Survey Prof. Paper 47* (1906), p. 89.

[3] B. L. Clark, "The Fauna of the San Pablo Group of Middle California," *Univ. Calif. Pub., Bull. Dept. Geol.*, Vol. 8, No. 22 (1915).

the San Pablo group. Trask,[1] in his intensive study of the lower divisions of the San Pablo group, did not find *P. pabloensis*.

The work of Clark, and of Trask, also indicates that *Ostrea titan* is restricted to the upper San Pablo, that *Ostrea bourgeoisii* ranges through the San Pablo group, and that *Cerithium rodeoensis* is restricted to the upper San Pablo. *Calyptraea filosa* and *Trophosycon nodiferum* are said to range from Miocene to lower Pliocene.

SUBDIVISIONS OF THE MODELO FORMATION

The faunal evidence presented in the foregoing sections seems to prove rather conclusively that the "Lower Modelo sandstone" is of Temblor (Topanga = middle Miocene) age, and that certain sandstones of the uppermost Modelo are of upper San Pablo (uppermost Miocene) age. No unconformities are known in the type section of the Modelo, or between the Modelo and the underlying beds of Vaqueros age, and no fossils representative of lower San Pablo are known from this region. Precise subdivisions may not be made, but it is believed that correlations may be made which will prove essentially correct.

In the opinion of the writers the type Modelo may best be divided into three formations. The lower of these should include the "Lower Modelo shale," the "Lower Modelo sandstone," and the "Middle Modelo shale" of Kew. This sequence of strata is believed to be of Temblor (Topanga = middle Miocene) age. The middle formation should include the "Upper Modelo sandstone," and the lower part of the "Upper Modelo shale" of Kew. No fossils have been found in this middle division but, as it is known to be part of a conformable series, with Temblor strata below and upper San Pablo strata above, it is probable that it is the correlative of the lower San Pablo (Briones and Cierbo = lower part of upper Miocene) of central California. The upper formation should include a certain upper part of the "Upper Modelo shale" of Kew. This formation is believed to be of the same age as the upper San Pablo (Santa Margarita, in restricted sense of B. L. Clark) of central California.

It is suggested that the name Topanga be used for the lower formation, and Santa Margarita for the upper formation. The middle formation may very will be called Modelo (in restricted sense) until the discovery of fossils may permit a precise correlation. Although precise correlations may not be made with the incomplete knowledge now avail-

[1]Parker D. Trask, "The Briones Formation of Middle California," *Univ. Calif. Pub., Bull. Dept. Geol.*, Vol. 13, No. 5 (1922).

able, it is believed that the restricted Modelo formation of Santa Clara Valley is equivalent to the Monterey shales of the Salinas Valley and San Joaquin Valley. The term Monterey, as used in this correlation, is restricted to post-Temblor, pre-Santa Margarita strata.

TABLE I

CORRELATION TABLE — MODELO FORMATION

Type Section of Modelo		*Central California and San Joaquin Valley*
Hudson and Craig	Eldridge & Arnold and Kew	B. L. Clark, F. M. Anderson, and others
Santa Margarita (upper San Pablo)	Upper shale	Upper San Pablo
Modelo (restricted sense)	Upper sandstone	Lower San Pablo (Briones and Cierbo)
Topanga	Middle shale Lower sandstone Lower shale	Temblor

UPPER MIOCENE NORTH OF MODELO TYPE SECTION

Certain strata which were included by Kew[1] in the Pico (lower Pliocene) formation, in the Reasoner Canyon area, north of the type section of the Modelo, contain fossils of unmistakably upper San Pablo age. Among other forms determined by A. J. Tieje were *Ostrea titan* and *Pecten bilineatus*. The beds containing this fauna rest with pronounced unconformity upon siliceous shale and arkose sandstones, which are thought to represent the Modelo (in restricted sense) formation.

SUMMARY AND CONCLUSIONS

The type section of the Modelo formation seems to represent continuous deposition from the close of Vaqueros to the end of the Miocene period.

The Modelo formation as originally defined consists of three divisions, which have the rank of formations. The lower division is of Temblor (Topanga = middle Miocene) age, and it is suggested that the name Topanga be used for this formation. The upper division is of uppermost Miocene (upper San Pablo = Santa Margarita) age, and it is

[1] *Op. cit.*, geologic map.

suggested that the name Santa Margarita be used for this formation. The middle division is believed to be of lower San Pablo (Briones and Cierbo) age, and it is suggested that the name Modelo be retained for this part of the original "Modelo formation."

A rather severe unconformity exists at the base of the Santa Margarita strata, north of the type section of the "Modelo formation." No evidence of such unconformity was found on the south.

DISCUSSION

TRINITY OF TEXAS

I have read with great interest the excellent paper by H. C. Vanderpool in the *Bulletin* of November, 1928, entitled "A Preliminary Study of the Trinity Group in Southwestern Arkansas, Southeastern Oklahoma, and Northern Texas," and wish to compliment him upon its excellence.

In this paper, however, I observe an erroneous statement pertaining to the history of the nomenclature of this group, which I must correct. Referring to the Comanchean series, the author states:

> The lowest group was first called the Bosque division by Taff [J. A. Taff, *Texas Geol. Survey 3d Ann. Rept.* (1891), p. 280] in his report on the Cretaceous of Texas. R. T. Hill, in his report on the Mesozoic rocks of Arkansas (R. T. Hill, *Arkansas Geol. Survey Ann. Rept. for 1888*, Vol. 2, p. 116), and later in his classic work on the geology of the Black and Grand Prairies of Texas (*U. S. Geol. Survey 21st Ann. Rept.* (1901), Pt. 7), named it the Trinity division.

The inference in this statement that the name Bosque division has priority over that of the Trinity division is erroneous, as is shown by the following proofs.

The paper by Mr. Taff, referred to by Mr. Vanderpool, was published in the Third Annual Report of the Texas Geological Survey in the latter half of the year 1892.[1] Prior to that time, between 1886 and 1893, as may be verified by consulting the papers given in the accompanying list, I had published no less than twenty papers on the Cretaceous formations of the Texas region, n m any of which the terms "Trinity sands," "Trinity division," and "Trinity formation" had been defined and used. The titles of these papers are given in Nickel's "Bibliography of the Geological Literature of North America" *U. S. Geol. Survey Bull. 746*, pp. 495-97.

Crude as the nomenclature of my early papers on the southwestern Cretaceous may now appear, one must remember that the evolution of the present names, mostly of my invention, was a matter of long years of tedious field work.

The "Trinity sands" were first announced and described under the name of the "Dinosaur sands" in my original paper on the Cretaceous of Texas.[2] The name was changed to Trinity sands not long thereafter, and as such it was re-described in many subsequent papers.

[1] Mr. Taff's paper was published in the summer of 1892 in the *Third Annual Report of the Geological Survey of Texas, 1891*. That it was not published until the summer of 1892 is testified (1) by the date on the title page, (2) by the date on the library card slips in the front of the book, and (3) by the date, May 1, 1892, of the state geologist's letter of transmittal.

[2] "Topography and Geology of the Cross Timbers of Texas," *Amer. Jour. Sci.* (April, 1887).

The group name "Trinity division," used for the sands plus an overlying limestone member later designated as the "Glen Rose," was apparently first used by me in *Science* of January 13, 1888, and published with amplified descriptions of its occurrence, extent, and paleontology in the *Second Annual Report of the Arkansas Geol. Survey* (Little Rock, 1888), five years before the invention of the term "Bosque division" by Taff, mentioned by Vanderpool.

Taken serially, the discovery, position, distribution, correlation, and classification of the two great series of Cretaceous strata of Texas may be clearly traced in my successive writings. As far as I was concerned, the preliminary work of classification of the Comanche series practically culminated in a paper read before the Geological Society of America, December 30, 1890, entitled "The Comanche Series of the Arkansas-Texas Region," which was published in *Bulletin 2* of the society, pp. 503-28 (May 5, 1891), more than a year befor Mr. Taff's book proposing the term "Bosque division" was transmitted to the printer (May, 1892).

This paper of mine fully defined and described the term "Trinity division" as it is used to-day. On page 505 I stated: "During the past year I have discovered that the beds described under this general term 'Trinity division' really included the stratigraphic subdivisions separated by distinct lithologic characteristics, the Trinity or basal sands, and the Glen Rose, or alternating beds, respectively." This passage introduced the name "Glen Rose" for the upper or limestone members of the group.

In reality, this paper was a summarizing of the publication in condensed form of my attempts during all of the preceding years to make a satisfactory classification and nomenclature of the formations of the Comanche series, and I do not see where this earlier paper of mine failed to give one essential fact of classification which appeared in Taff's paper of a year later. It represented the consummation of all of my previous work on this subject, and its accompanying table and descriptions, with a few trivial exceptions, are practically the same as those which were later used in my "Black and Grand Prairies" and as I would use them to-day. This table of the formations was as follows:

Definition of the Terranes
Constitution of the Comanche Series
- C. The Washita or Indian Territory Division
  - 11. The Denison Beds
  - 10. The Fort Worth Limestone
  - 9. The Duck Creek Chalk
  - 8. The Kiamitia Clays or Schloenbachia Beds
- B. The Fredericksburg or Comanche Peak Division
  - 7. The Goodland Limestone
  - 6. The Caprina Limestone
  - 5. The Comanche Peak Chalk
  - 4. The Gryphaea Rock and Walnut Clays
  - 3. The Paluxy Sands
- A. The Trinity Division
  - 2. The Glen Rose or alternating beds
  - 1. The Trinity or Basal Sands

This paper also showed the distribution of the basement sands in Texas, New Mexico, and Indian Territory, practically as we know them to-day. It also first defined and described the terms Glen Rose formation, Paluxy sands, Goodland limestone, Walnut, Kiamitia, and Denison beds.

The only defect of the section given viewed from the present-day standpoint is that the table places the Goodland above the Caprina and Comanche limestones, instead of coördinate with them. But the text explains that they are identical with it (p. 514), and that "the Goodland limestone resembles the Caprina in hardness and the Comanche Peak in its fauna."

The only term used in my later publications, not included in this one, is "Edwards limestone," a name which I intended to use for the combined Comanche Peak and Caprina limestones of the Colorado River section, but which is now variously used in western Texas.

The term "Denison beds" of this section has been abandoned by the United States Geological Survey nomenclature. I consider this an ill-advised action and personally shall continue to use it, for the group name represents a clearly distinguishable category of formations represented by the Weno, Pawpaw, Main Street, Grayson, and Buda[1] formations in the Denton County section and their correlatives, the Del Rio and Buda limestones of the south Texas sections.

Not only was Mr. Taff's paper containing his definition of the term "Bosque division" amply preceded by the previously mentioned papers in the Arkansas Survey Report and the Bulletin of the Geological Society of May, 1891, but a third and more comprehensive report on the occurrence of the Trinity Division was published by me in February, 1892, prior to the use of the name "Bosque division." This was the report "On the Occurrence of Artesian and Other Underground Waters in Texas, Eastern New Mexico, and Indian Territory West of the 97th Meridian," of which two editions were printed in the first months of 1892.[2] Confusion is added to the subject because the issuance

[2]"On the Occurrence of Artesian and Other Underground Waters in Texas, Eastern New Mexico, and Indian Territory West of the Ninety-Seventh Meridian," by Robert Thomas Hill, Assistant Geologist for Texas West of 97°, the Indian Territory, and Eastern New Mexico, being Part 3 of *Sen. Ex. Doc. 41*, 52d Cong., 1st sess., printed at Washington, D. C., February, 1892, entitled "Final Geological Reports of the Artesian and Underflow Investigation between the 97th Meridian of Longitude and the Foothills of the Rocky Mountains," by Robert Hay, F. G. S. A., Chief Geologist, Office of Irrigation Inquiry, U. S. Department of Agriculture.

of this paper is wrongly dated as "1893" instead of "1892" in Nickel's Bibliography, *U. S. Geol. Survey Bull. 746*, p. 496, the first separate having been printed in February, 1892.

This Artesian Report printed by the National Government was practically an amplification of the paper in the Bulletin of the Geological Society of America previously referred to, and it might also be considered a preliminary edition of my Black and Grand Prairies monograph of 1908. It also contained important maps, descriptions, and profile sections showing the Trinity division.

The successful appearance of this government report six months prior to Taff's paper in the Fourth Annual Texas Report of 1892, in which the term "Bosque division" was used for the first and only time, gave great discomfort to my politico-scientific opponents at Austin. Taking advantage of many

[1]The discovery of the characteristic limestone and fossils of the Buda formation in Denton County, north Texas, was announced by me in more recent years.

typographic errors in the hastily printed first edition, one of them wrote a diatribe upon it.

The inadequacy of Taff's term "Bosque division" is further shown by the fact that it was abandoned by Taff himself in his later and excellent folios on the Indian Territory.

I would not have written this correction of Mr. Vanderpool's statement were it not for the fact that for nearly forty years I have silently endured many other similar misstatements of my work in the scientific literature, as well as credits to Mr. Taff similar to the one mentioned on page 58 in Bulletin 780-B of the U. S. Geological Survey by H. W. Hoots.

It is a great injustice to both Mr. Taff and myself to credit him with the work which I did with infinite pains and labor during the years prior to his having first seen the Cretaceous formations of Texas. These remarks are not made in disparagement of him, for whom and for whose most excellent work I have only the profoundest respect, esteem, and admiration. He has done enough outstanding research of his own without unnecessarily being burdened with mine. Above all, my only intention is to set the scientific record straight in order to prevent the people of my state, Texas, from accepting as facts these and other distorted statements of my scientific record which have been put forth. Neither are any reflections meant upon the excellent works and characters of the other persons mentioned. They have only done what others have done before them.

LIST OF PUBLICATIONS ON THE CRETACEOUS OF TEXAS

(by Robert T. Hill, 1896 to 1903, containing definitions of, and references to, the Trinity sands and Trinity division).

1. 87, "The Present Condition of Knowledge of the Geology of Texas," *U. S. Geol. Survey Bull. 45* (1887).

2. 87*a*, "The Topography and Geology of the Cross Timbers and Surrounding Regions in Northern Texas," *Amer. Jour. Sci.* (3), Vol. 33 (1887), pp. 291-303.

3. 87*b*, "The Texas Section of the American Cretaceous," *Amer. Jour. Sci.* (3), Vol. 34 (1887), pp. 287-309.

4. "Neozoic Geology of Southwestern Arkansas," *Arkansas Geol. Survey Ann. Rept. 1888.*

5. 88*a*, "The Trinity Formation of Arkansas, Indian Territory, and Texas," *Science*, 11:21 (1888).

6. 88*c*, "The Geology of Texas," *Texas School Jour.*, n. s., 6 (1888), pp. 143-45.

7. 88*d*, "Notes upon Texas Section of the American Cretaceous" (abst.), *Amer. Assoc. Pr.*, 36:216 (1888).

8. 89, "A Preliminary Annotated Check List of the Cretaceous Invertebrate Fossils of Texas, Accompanied by a Short Description of the Lithology and Stratigraphy of the System," *Texas Geol. Survey Bull. 4* (1889).

9. 89*a*, "Check List of the Invertebrate Fossils from the Cretaceous Formations of Texas," (Austin, Texas, 1889).

10. 89*b*, "Roads and Material for Their Construction in the Black Prairie Regions of Texas," *Univ. of Texas* (December, 1889).

11. 89*c*, "Paleontology of the Cretaceous Formations of Texas," Pt. 1, *Univ. of Texas School Geology* (1889).

12. 89*d*, "Events in North American Cretaceous History Illustrated in the Arkansas-Texas Division of the Southwestern Region of the United States," *Amer. Jour. Sci.* (3), Vol. 37 (1889), pp. 282-90.

13. 89*e* (and R. A. F. Penrose, Jr.), "Relation of the Uppermost Cretaceous Beds of the Eastern and Southern United States, and the Tertiary-Cretaceous Parting of Arkansas and Texas," *Amer. Jour. Sci.* (3), Vol. 38 (1889), pp. 468-73.

14. 89*f*, "A Portion of the Geologic Story of the Colorado River of Texas," *Amer. Geologist*, Vol. 3 (1889), pp. 287-99.

15. 89*g*, "The Foraminiferal Origin of Certain Cretaceous Limestones and the Sequence of Sediments in North American Cretaceous," *Amer. Geologist*, Vol. 4 (1889), pp. 174-77.

16. 89*h*, "A Brief Description of the Cretaceous Rocks of Texas," *Geol. Survey of Texas 1st Ann. Rept.* (1889).

17. 90, "A Brief Description of the Cretaceous Rocks of Texas and Their Economic Value," *Texas Geol. Survey Ann. Rept. 1* (1890), pp. 103-41.

18. 90*c*, "The Fossils of the Trinity Beds," *Amer. Geologist*, Vol. 5 (1890).

19. 90*d*, "Exploration of the Indian Territory and the Medial Third of Red River," *Amer. Geologist*, Vol. 6 (1890), pp. 252-53.

20. 90*e*, "The Texas Cretaceous," *Amer. Geologist*, Vol. 6 (1890), pp. 253-54.

21. 91, "The Comanche Series of the Arkansas-Texas Region," *Bull. Geol. Soc. Amer.* (1891).

The foregoing publications are listed in the "Bibliography of the Geological Literature of North America," *U. S. Geol. Survey Bull. 746*. In addition, the following important work was published just prior to, or contemporaneously with, Mr. Taff's work of September, 1892.

22. 92, "On the Occurrence of Artesian and Other Underground Waters in Texas, Eastern New Mexico, and Indian Territory West of the 97th Meridian," 52nd Congress 1st sess., *Senate Ex. Doc. 41*, Pt. 3 (February), pp. 41-166. (The first edition of this work was run through the Government printing office in a single night, without proof reading, and contained many typographical mistakes. A second, revised edition, which alone should be consulted, was immediately reprinted.)

ROBERT T. HILL

LOS ANGELES, CALIFORNIA
March 18, 1929

REVIEWS AND NEW PUBLICATIONS

Geophysical Prospecting, 1929. Papers presented before the American Institute of Mining and Metallurgical Engineers (New York City, 1929). 676 pp., many photographs and diagrams. Cloth. 6 x 9 inches. Price, $5.00.

The adoption of various geophysical prospecting methods as an aid to the geologist has aroused considerable interest among workers in the oil and mining industries. Oil companies are establishing geophysical departments or are having such work done by consulting firms. Geophysical methods have been tried and proved valuable in certain areas. Their application will probably be increased in the future.

As the editors state in the preface of this book, only a few of the methods now practised are entirely new, although relatively little use has been made of them until recently. A salient feature of geophysics was further stated in the preface where it was pointed out that geophysical measurements are practically never made on the valuable resource sought, but upon the geologic features affecting that resource's accumulation. The physicist is dependent, therefore, on geological reasoning for the final interpretation and practical application of his data. The development of applied geophysics has been rapid, but has been handicapped by lack of men expertly trained in both physical and geological sciences.

Geophysical Prospecting contains a collection of 27 separate papers on the electric, magnetic, gravimetric, and seismic methods of applied geophysical exploration. Each method has been treated by an outstanding authority in that field, and it is believed that a comprehensive outline of present-day results is given. The editors are planning an additional volume of later papers on the same subjects, which is understood to be already in process of preparation.

It is gratifying to see the frank interchange of ideas and scientific information among scientific-minded men, realizing, at the same time, the existence of keen competition to-day.

HOWARD S. BRYANT

TULSA, OKLAHOMA
March 27, 1929

Le Pétrole en Pologne (Oil in Poland). By MICHEL ALBERG. Librarie Centrale et Universitaire (Lousanne, 1929). 166 pp. Appendices, 46 pp. Price, 7.20 francs.

In this work, Dr. Alberg deals primarily with the economic phases of the industry, and does not give any geological information. The book is of statistical and historical value. By chapters, the contents are as follows: (1)

historical review; (2) producing areas, their estimated reserves, drilling methods, concessions, storage, transport and labor questions; (3) refining (in statistical detail); (4) marketing; (5) subsidiary industries, including gas and gasoline, ozokerite, as well as manufacture of oil field machinery; (6) capital structure, in special reference to foreign financing, particularly French and American; and (7) the government and the oil industry.

BASIL B. ZAVOICO

TULSA, OKLAHOMA
April 4, 1929

RECENT PUBLICATIONS

MADAGASCAR

"Madagascar and its Oil Lands," by Arthur Wade. *Jour. Inst. Petrol. Tech.*, Vol. 15, No. 72 (February, 1929), pp. 2-33, illus.

MONTANA-WYOMING

"The Origin of the Siliceous Mowry Shale of the Black Hills Region," by W. W. Rubey. *U. S. Geol. Survey Prof. Paper 154-D* (1929). Price, $0.10.

OKLAHOMA

"Map of Oil and Gas Fields of Oklahoma." Originally published in 1928 as a part of *Oklahoma Geol. Survey Bull. 40-Q.* Two colors. Price, $0.05.

"The Pennsylvanian System in the Ardmore Basin," by C. W. Tomlinson. *Oklahoma Geol. Survey Bull. 46* (Norman, 1929), 79 pp., 20 plates, 3 figs. Price, $0.57.

RUSSIA

"Die Schurfbohrungen auf Erdöl in der U. d. S. S. R." (Drilling for Oil in the U. S. S. R.). *Petroleum Zeits.* (March 13, 1929), pp. 344-48. Abstract and review from the Russian.

"Der derzeitige Stand der Explorationsarbeiten der 'Asneft'" (Status of Exploration Work of Asneft Trust, Baku). *Petroleum Zeits.* (March 13, 1929), pp. 348-51. Abstract from the Russian.

UTAH

"The San Rafael Swell, Utah," by James Gilluly. *U. S. Geol. Survey Bull. 806-C.* Superintendent of Documents, Washington, D. C. Price, $0.25.

WYOMING

"The Rock Creek Oil Field and Adjacent Areas in Carbon and Albany Counties, Wyoming," by C. E. Dobbin, H. W. Hoots, C. H. Dane, and E. T. Hancock. *U. S. Geol. Survey Bull. 806-D.* Superintendent of Documents, Washington, D. C. Price $0.20

"Geology and Possibilities of Frannie Field, Park County, Wyoming," by Charles T. Lupton. *Inland Oil Index* (Casper, Wyoming, March 29, 1929).

THE ASSOCIATION LIBRARY

Headquarters acknowledges library accessions:

FRANCE

From C. R. Hoffmann:

"Le gisement de calcaire asphaltique de Lobsann et son origine," by J. O. Haas and C. R. Hoffmann

PALEONTOLOGY

From W. Storrs Cole:

"Three New Claiborne Fossils"

THE ASSOCIATION ROUND TABLE

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The Executive Committee has approved for publication the names of the following applicants for membership in the Association. This does not constitute an election, but places the names before the membership at large. If any member has information bearing on the qualifications of these applicants, please send it promptly to J. P. D. Hull, Business Manager, Box 1852, Tulsa, Oklahoma. (Names of sponsors are placed beneath the name of each applicant.)

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FOURTEENTH ANNUAL MEETING OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS, FORT WORTH, TEXAS, MARCH 21-23, 1929

More members registered at the fourteenth annual meeting than at any other meeting in the history of the Association: 836. More members of the Association live in Texas than in any other state: 591. Our total membership enrollment is 2,126, of which 1,496 are active members. Of the 836 members in attendance at Fort Worth, 621 were active members eligible to vote in the annual elections, and of these 466 cast their ballots for the most evenly matched nominees in any A. A. P. G. annual election. Those who have periodically and publicly lamented the lack of general interest in pre-convention politics must have been pleased with this year's activity. There were two nominees for each office,—almost three.

Each annual meeting is best remembered by some outstanding event or feature. The Fort Worth convention had several claims for distinction. The decision of the committee to collect a convention registration fee was a commendable start toward making our meetings self-sustaining. For less than the price of the old-time banquet tickets, this year's registrant was given a handful of admissions covering the illustrated lecture by Professor Berkey on the Gobi Desert adventure, the dance, the barbecue, and the rodeo.

Of course everyone in attendance realized the continued growth of the Association,—financially, scientifically, and in number of members. The annual banquet of other years is evidently outgrown. The stockyard barbecue (second largest in the history of Fort Worth) and rodeo were at once whole-heartedly hospitable and breath-taking—typically Fort Worth—and subtly spiced with a dash of the comic by our own inimitable team—Donoghue and Thomas, or Thomas and Donoghue.

Presentation of the technical program was mechanically improved this year by the use of the microphone and amplifiers and by pre-printed distribution of important papers in so far as manuscripts were available previous to the meeting.

Privately arranged luncheons, dinners, and confabs blossomed all over town, to renew many memories of fraternity, college, and oil company. The general business committee completed its work of steering the Association in the only high-powered session of that important body that ever reached agreement without resorting to a midnight meeting. The executive committee held two meetings. The research committee outlined a new course of action for encouraging fundamental research in petroleum geology.

Ladies' entertainment included a complimentary luncheon at the Fort Worth Club, an informal dance in the Crystal ball room of The Texas Hotel, and a bridge luncheon at the River Crest Country Club. The number of women who are geologists and members of the Association in their own right seems to be larger at each meeting. This year they enjoyed a luncheon at the Woman's Club and organized for their special interests.

The annual golf tournament was held at the River Crest Country Club. Following are the winners:

Low gross score—I. R. Sheldon, Wichita Falls, Texas
Second low gross score—E. T. Merry, Fort Worth, Texas
First handicap prize—A. F. Crider, Shreveport, Louisiana
Second handicap prize—T. C. Cash, Tyler, Texas
Third handicap prize—W. K. Esgen, Cisco, Texas

Honors in the J. Wallace Bostick golf trophy competition were as follows:

Member winner—A. F. Crider, Shreveport, Louisiana (score, 93; handicap, 25; net, 68)
Guest winner—William McGinley, Fort Worth, Texas (score, 95; handicap, 25; net 70)
Special—K. D. Harrison, San Angelo, Texas (score, 75; handicap, 5; net, 70)

The Society of Economic Paleontologists and Mineralogists elected the following officers: Marcus A. Hanna, president; John B. Reeside, Jr., vice-president; F. B. Plummer, secretary-treasurer; and Joseph A. Cushman, editor.

FORT WORTH GEOLOGICAL SOCIETY CONVENTION COMMITTEES

General.—J. Elmer Thomas, chairman; Ford Bradish, J. Earle Brown, David Donoghue, H. B. Fuqua, J. H. Jenkins, R. A. Liddle, B. E. Thompson, and C. P. Watson.
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Entertainment.—J. Earle Brown, chairman; Paul Buttermore, E. T. Merry, V. C. Perini, and R. R. Thompson.
Publicity.—Ford Bradish, chairman; Alan Bruyere, N. B. Livingston, and R. J. Metcalf.
Reception.—H. B. Fuqua, chairman; C. S. Miller, and Roy Reynolds.
Ladies.—C. P. Watson, chairman; Mrs. J. Earle Brown, Mrs. H. B. Fuqua, and Mrs. B. E. Thompson.
Registration.—David Donoghue, chairman; E. B. Stiles, vice-chairman; and W. W. Patrick.
Arrangements.—B. E. Thompson, chairman; Claude Dally, and C. E. Yager.

CONDENSED PROGRAM

WEDNESDAY, MARCH 20

10:00 A. M.	Executive committee (Texas Hotel)
2:00 P. M.	General business committee (Texas Hotel)

THURSDAY, MARCH 21

10:00 A. M.	Address of welcome—R. A. Liddle Welcome from Fort Worth—Amon G. Carter Acknowledgment—R. S. McFarland
10:30	Technical session
12:00 M.	Complimentary luncheon for ladies (Fort Worth Club)
2:00 P. M.	Technical session
4:45	Nomination of officers
8:00	Public lecture: "Experiences and Observations in the Gobi Desert of Mongolia"—Charles P. Berkey (Civic Theater)
10:00	Informal dance (Crystal Ballroom, Texas Hotel)

FRIDAY, MARCH 22

8:00 A. M.	Ballot boxes open
9:30	Technical sessions
12:30 P. M.	Ladies' bridge luncheon (River Crest Country Club)
12:30	Luncheon of Society of Economic Paleontologists and Mineralogists (Fort Worth Club)
2:00	Technical sessions
2:30	Business session, S. of E. P. and M.
6:00	Ballot boxes close
7:00	Barbecue (Southwestern Exposition Grounds)
8:15	Rodeo (Southwestern Exposition Grounds)

SATURDAY, MARCH 23

9:00 A. M.	Technical sessions
10:00	Annual business meeting
11:30	Business session and election, S. E. P. and M.
12:30 P. M.	Luncheon for ladies in paleontology and geology (Woman's Club)
2:00	Technical sessions
3:00	Comanche field trip
4:00	Old and new executive committees

SUNDAY, MARCH 24

7:30 A. M.	Pennsylvanian field trip

PAPERS

SYMPOSIUM ON THE STRATIGRAPHY OF THE PERMIAN BASIN OF SOUTHWESTERN UNITED STATES: ALEX W. McCOY, CHAIRMAN

1. Notes on the Permian Stratigraphy and Structure of Parts of Southeastern New Mexico and Southwestern Texas—W. GRANT BLANCHARD, JR., and MORGAN DAVIS
2. Correlation of the Pennsylvanian and Permian between the Glass Mountains and the Delaware Mountains—I. A. KEYTE
3. Permian Stratigraphy of Southeastern New Mexico and Adjacent Portions of Western Texas—K. H. CRANDALL
4. The Castile Formation Re-Defined—LON D. CARTWRIGHT, JR.
5. Stratigraphy of Outcropping Carboniferous and Permian Rocks of Trans-Pecos Texas—PHILIP B. KING and ROBERT E. KING
6. Stratigraphic Controls in the Texas Permian—ROBIN WILLIS
7. Correlation of the Pennsylvanian and Permian of Northern Arizona, Southern Utah, Southwestern Colorado, and Northern New Mexico—J. B. REESIDE and A. A. BAKER
8. Correlation of the Pennsylvanian from North-Central Texas to Central Oklahoma— R. C. MOORE
9. The Triassic of West Texas—JOHN EMERY ADAMS
10. A Correlation of Permian Outcrops on the Eastern Side of the West Texas Basin —A. M. LLOYD and W. C. THOMPSON
11. Capitan Limestone and Associated Formations of Texas and New Mexico— E. RUSSELL LLOYD
12. Magdalena-Abo Formations of New Mexico—I. A. KEYTE

GEOPHYSICAL

1. Tables of Terrane Correction—DONALD C. BARTON
2. The Hotchkiss Superdip: A New Magnetometer—NOEL H. STEARN

3. The Oil-WIll-Decline Formula: Hyperbolic or Polynomial?—ROSWELL H. JOHNSON
4. The Mercury Method for the Measurement of the Volume of Rock Specimens in Porosity Determinations—W. B. Gealy
5. A Classification of Oil Reservoirs—W. B. WILSON
6. Least Square Adjustment of Magnetometer and Torsion Balance Surveys—DONALD C. BARTON
7. Helium—Its Probable Origin and Concentration in the Amarillo Field—PAUL RUEDEMANN and L. M. OLES

STRUCTURAL GEOLOGY

1. Tectonic Classification of Oil Fields in the United States—WALTER A. VER WIEBE
2. Review of Production and Developments in West Texas—A. R. DENISON
3. Tectonics of West Texas and Eastern New Mexico—BEN C. BELT
4. Review of Discoveries and Developments in East Texas in 1928—SIDNEY A. JUDSON
5. Geology of East Texas, with a Discussion on Salt Movements and with Special Reference to Mt. Sylvan Salt Dome—E. A. WENDLANDT and G. MOSES KNEBEL
6. *En Échelon* Tension Fissures and Faults—THEODORE A. LINK
7. Structural Development in the Texas Permian—ROBIN WILLIS

MISCELLANEOUS

1. Revision of Formation Contacts and Mapping of the Pennsylvanian in North-Central Texas—F. B. PLUMMER
2. The Texon Deep Well in Reagan County, Texas—E. H. SELLARDS and WALDO WILLIAMS
3. Oil Development in Michigan during 1928—THERON WASSON
4. Some Geologic and Economic Notes on the Venezuelan Oil Developments—E. B. HOPKINS and H. J. WASSON
5. The Geology of the Kettleman Hills, California—W. D. KLEINPELL and R. D. REED
6. The Shale-Gas Industry of Eastern Kansas—HOMER H. CHARLES and JAMES E. PAGE
7. Pre-Mississippian Sediments in Central Kansas—FANNY CARTER EDSON
8. Pre-Pennsylvanian Stratigraphy of the Front Range in Colorado—A. E. BRAINERD, H. L. BALDWIN, and I. A. KEYTE
9. Notes on the Pennsylvanian Section at Lost Lake, Colorado—A. E. BRAINERD, I. A. KEYTE, and H. L. BALDWIN
10. Structural Features of the West Franklin Formation of Southwestern Indiana—ROBERT R. SHROCK and CLYDE A. MALOTT
11. Rôle of Geologic Structure in the Accumulation of Petroleum—FREDERICK G. CLAPP
12. Notes on the Oil Fields and Structure of the Sweetgrass Arch, Montana—THOMAS B. ROMINE
13. Geology of the Larremore Area, Caldwell County, Texas—ALBERT WILLIAM WEEKS
14. Structural Geology and Stratigraphy of Southwest Oklahoma—CLYDE M. BECKER
15. Carbon Ratios and Oil Gravities in the Rocky Mountain Region—C. E. DOBBIN
16. Aerial Surveys for Petroleum Reconnaissance—STUART MORIER
17. The Stratigraphy and Structure of the Smoky Hill Chalk in Western Kansas—WILLIAM L. RUSSELL
18. Local Subsidence in Western Kansas—WILLIAM L. RUSSELL

19. The Environment of Pennsylvanian Life in North America (Presidential Address of the President of the Society of Economic Paleontologists and Mineralogists) —R. C. MOORE
20. Unconformities in the Upper Cretaceous Series of Texas—L. W. STEPHENSON
21. Stratigraphic Information Obtained from Drilling into the Lower Cretaceous in Southern Arkansas and Northern Louisiana—W. C. SPOONER, R. T. HAZZARD, and M. C. ISRAELSKY
22. The Problem of Crooked Holes—FREDERIC H. LAHEE
23. Geology of the Oil Fields of Poland—H. DE CIZANCOURT
24. The Cretaceous-Eocene Unconformity in Venezuela—WILLIAM F. JONES and W. L. WHITEHEAD
25. The Monterey Group of California—J. E. EATON
26. Undergraduate Preparation for the Geologist—ELLIS W. SHULER
27. The Georgetown Formation of Central Texas and Its North Texas Equivalents —ROBERT H. CUYLER
28. Microthermal Studies of Some "Mother Rocks" of Petroleum from Alaska—TAISIA STADNICHENKE
    With description of the Fossil Plants—DAVID WHITE
29. The Surface and Subsurface Distribution of Silurian and Devonian Rocks of Texas, Oklahoma, Arkansas, Missouri, and Iowa—IRA CRAM

PALEONTOLOGY

1. Claiborne Subsurface Sections of Eastern Texas and Western Louisiana—ALVA C. ELLISOR
2. A Study in Variations in Recent Faunas along the Gulf Coast of Texas and Louisiana as Found in the Transition from Fresh to Marine Environments—MARCUS A. HANNA, W. G. PARKER, and KARL E. YOUNG
3. Cretaceous and Lower Tertiary Diatoms from Texas and Louisiana—G. DALLAS HANNA and MARCUS A. HANNA
4. A Section in Peninsular Florida—E. R. APPLIN and P. L. APPLIN
5. Notes on the Del Rio and Buda Formations in West Texas—TIMOTHY W. STANTON
6. Cretaceous Echinoids of the Genus Macraster—W. S. ADKINS
7. Upper Cretaceous of Maverick County, Texas—KARL E. YOUNG
8. Some Upper Cretaceous *Foraminifera* from Near Coalinga, California—JOSEPH A. CUSHMAN and C. C. CHURCH
9. Notes on the Cretaceous of Lower California—F. M. ANDERSON and G. DALLAS HANNA
10. Faunal Relations of the Pennsylvanian at McCoy, Colorado—I. A. KEYTE
11. Youngest Faunas of the Non-Red Permian of Southern Kansas and Northern Oklahoma—MARGARET FULLER BOOS
12. Presidential Address: The Environment of Pennsylvanian Life in North America —RAYMOND C. MOORE
13. The Problem of Re-Worked *Foraminifera* and Its Bearing on Correlation—JOSEPH A. CUSHMAN
14. Fish Otoliths, Their Occurrence and Value as Stratigraphic Markers—ROBERT B. CAMPBELL
15. The Preparation of Illustrations of Fossils—G. DALLAS HANNA
16. Material on the Use of Slides—HELENE JEANNE PLUMMER
17. Galena and Sphalerite in the Fayette at Moore Dome, Fort Bend County, Texas —MARCUS A. HANNA

The total registration at the meeting was 1,457: 3 honorary members; 621 active members; 212 associate members; 27 applicants; 351 guests (women); and 243 guests (men). Several hundred did not register.

MEMBERS REGISTERED AT FOURTEENTH ANNUAL MEETING

HONORARY

Decker, Charles E., Norman, Okla.
Hill, Robert T., Los Angeles, Calif.
Udden, Johan August, Austin, Tex.

ACTIVE

Absher, Wm. F., Bartlesville, Okla.
Ackers, A. L., Midland, Tex.
Adams, Frank C., Houston, Tex.
Adams, H. H., Fort Worth, Tex.
Adkins, W. S., Austin, Tex.
Aid, Herbert, Eastland, Tex.
Aldrich, G. Frank, Fort Worth, Tex.
Allan, Thos. H., Russell, Kan.
Allen, Bryant, Laredo, Tex.
Ames, Edward W., Cisco, Tex.
Ames, E. R., Houston, Tex.
Anderson, Carl B., Tulsa, Okla.
Anderson, G. E., Norman, Okla.
Andreen, Harry M., Tulsa, Okla.
Andrews, Sylvan H., Tulsa, Okla.
Applin, Paul L., Fort Worth, Tex.
Armstrong, J. M., Eastland, Tex.
Aronson, Sam M., San Angelo, Tex.
Artman, Geo. W., Amarillo, Tex.
Athy, Lawrence F., Ponca City, Okla.
Aurin, Fritz L., Ponca City, Okla.
Avery, C. Dwight, Washington, D. C.
Bace, A. C., Enid, Okla.
Baker, Charles L., Houston, Tex.
Bale, Hubert E., Oklahoma City, Okla.
Ball, Max W., Denver, Colo.
Baldwin, Harry L., Jr., Oklahoma City, Okla.
Banks, Thomas R., San Antonio, Tex.
Barnett, D. G., Wichita Falls, Tex.
Barrow, Leonidas T., San Antonio, Tex.
Barton, Donald C., Houston, Tex.
Bartram, John G., Denver, Colo.
Bauer, C. Max, Amarillo, Tex.
Bayer, H. M., Midland, Tex.
Bean, Ward C., Wichita Falls, Tex.
Beck, Elfred, Tulsa, Okla.
Becker, Clyde M., Chickasha, Okla.
Bell, Olin G., Laredo, Tex.
Belt, Ben C., Houston, Tex.
Benson, Dale L., Amarillo, Tex.
Benton, Louis B., Cisco, Tex.
Best, J. Boyd, Houston, Tex.
Bevier, George M., Houston, Tex.
Berger, Walter R., Fort Worth, Tex.
Bierman, Alfred C., Dallas, Tex.
Birk, Ralph A., Wichita Falls, Tex.
Birkett, Donald S., Atlanta, Ga.
Blanchard, W. Grant, Jr., Dallas, Tex.
Blackburn, William D., Fort Worth, Tex.
Blanpied, B. W., Tupelo, Miss.
Bloesch, Edward, Tulsa, Okla.
Bolyard, Garrett L., Cisco, Tex.
Bond, Lewis A., Pasadena, Calif.
Boos, C. Maynard, Bartlesville, Okla.
Borden, S. P., Shreveport, La.
Bostick, J. Wallace, Dallas, Tex.
Bowen, James P., Wichita Falls, Tex.
Bowman, Wayne F., Houston, Tex.
Boylan, Ebert E., New York, N. Y.
Boyle, Albert C., Jr., Laramie, Wyo.
Boyle, Walter J., Fort Worth, Tex.
Brace, Orval L., Roswell, N. Mexico
Bradish, Ford, Fort Worth, Tex.
Brainerd, Arthur E., Ponca City, Okla.
Brainerd, William F., Wichita Falls, Tex.
Branner, Geo. C., Little Rock, Ark.
Brantly, John E., Philadelphia, Pa.
Brauchli, Rud., Oklahoma City, Okla.
Brillhart, Norman W., Cisco, Tex.
Briscoe, Glenn O., San Angelo, Tex.
Brown, J. Earle, Fort Worth, Tex.
Brown, J. Marshall, Midland, Tex.
Brown, Prentice F., Midland, Tex.
Bruyere, Alan, Fort Worth, Tex.
Bullard, Fred M., Austin, Tex.
Bullard, Edgar F., Shreveport, La.
Bunn, John R., Ardmore, Okla.
Burchfiel, Hugh L., El Paso, Tex.
Burton, George E., Ardmore, Okla.
Burress, Walter M., Midland, Tex.
Burt, Roy A., Kansas City, Mo.
Butcher, Cary P., San Angelo, Tex.
Butcher, Seldon D., Shawnee, Okla.
Buttermore, Paul M., Fort Worth, Tex.
Butters, Roy M., San Antonio, Tex.
Bybee, Hal. P., San Angelo, Tex.
Byrd, David Harold, Brownwood, Tex.
Callahan, Drury V., Ardmore, Okla.
Campbell, Robert B., San Angelo, Tex.
Cannon, R. L., San Angelo, Tex.
Carlson, Charles G., Tulsa, Okla.
Carlton, Dave P., Houston, Tex.
Carney, Frank, Fort Worth, Tex.

Carpenter, M. E., Oklahoma City, Okla.
Cashin, D'Arcy M., Houston, Tex.
Cave, Harold S., Roswell, N. M.
Charles, Homer H., Tulsa, Okla.
Cheney, Charles A., Tulsa, Okla.
Cheney, M. G., Coleman, Tex.
Chisholm, William F., Shreveport, La.
Christner, D. D., San Angelo, Tex.
Clark, Chester C., Shreveport, La.
Clark, Clifton W., Wichita Falls, Tex.
Clark, Frank Rinker, Tulsa, Okla.
Clark, Glenn C., Ponca City, Okla.
Clark, Howard, Tulsa, Okla.
Clark, H. Smith, Fort Worth, Tex.
Clark, Stuart K., Ponca City, Okla.
Closuit, E. M., Fort Worth, Tex.
Clowe, Charles E., Ardmore, Okla.
Coffin, R. Clare, Denver, Colo.
Collingwood, D. M., Dallas, Tex.
Collins, Melvin J., San Angelo, Tex.
Conkling, R. A., Oklahoma City, Okla.
Cook, Carroll E., Austin, Tex.
Cooper, Herschel H., San Antonio, Tex.
Copeland, Richard G., El Dorado, Ark.
Corbett, Clifton S., New York, N. Y.
Cotner, Victor, Amarillo, Tex.
Cottingham, Virgil E., San Angelo, Tex.
Cotulla, Reuben E., Eastland, Tex.
Cram, Ira H., Tulsa, Okla.
Crider, Albert F., Shreveport, La.
Crandall, Richard R., Los Angeles, Calif.
Crum, Harry E., Amarillo, Tex.
Cruse, John S., Jr., Houston, Tex.
Cullen, Ronald J., Tulsa, Okla.
Cushman, Joseph A., Sharon, Mass.
Dake, Charles L., Rolla, Mo.
Dakin, Francis W., Evanston, Ill.
Dally, Claude F., Fort Worth, Tex.
Daniels, Harold G., Abilene, Tex.
Daniels, James I., Ponca City, Okla.
Danvers, Don, Corsicana, Tex.
Davis, Thornton, Wichita Falls, Tex.
Davies, Fred A., Denver, Colo.
Day, Willard L., Amarillo, Tex.
Dean, D. P., Tulsa, Okla.
Dean, P. C., Eastland, Tex.
Decius, L. Courtney, San Francisco, Calif.
de Coussér, Kurt H., Tulsa, Okla.
Denison, A. R., Fort Worth, Tex.
DeWolf, Frank W., Houston, Tex.
Deussen, Alexander, Houston, Tex.
Disney, Orville A., San Antonio, Tex.
Dissinger, Earl, Houston, Tex.
Dobbin, Carroll E., Denver, Colo.
Dodson, Floyd C., San Angelo, Tex.
Donoghue, David, Fort Worth, Tex.
Dorchester, Charles M., Shreveport, La.
Dorsey, Geo. Edwin, Dallas, Tex.
Doyle, John J., Shreveport, La.
Dreher, Otto, The Hague, Holland
Dugan, Ira E., Ponca City, Okla.
Dunlevy, Robert B., Winfield, Kan.
Dunn, George V., Tulsa, Okla.
Duston, Arthur W., Tulsa, Okla.
Earl, Will F., Tulsa, Okla.
Eby, J. Brian, Houston, Tex.
Edson, Dwight J., San Angelo, Tex.
Edson, Fanny C., Tulsa, Okla.
Edwards, Everett C., San Angelo, Tex.
Edwards, Merwin G., South Pasadena, Calif.
Elledge, Emmett R., Breckenridge, Tex.
Elliott, John E., Los Angeles, Calif.
Eirich, Constance G., Tulsa, Okla.
Ellisor, Alva C., Houston, Tex.
Emch, John W., San Angelo, Tex.
Evans, Noel, Ponca City, Okla.
Eyoub, Djevad, Tampico, Mexico
Fash, Ralph H., Fort Worth, Tex.
Ferguson, John L., Tulsa, Okla.
Ferguson, Kenneth S., Denver, Colo.
Finch, Elmer H., Shreveport, La.
Fisher, Cassius A., Denver, Colo.
Fletcher, Corbin D., Shreveport, La.
Floyd, Florin W., Tulsa, Okla.
Ford, Carl S., Enid, Okla.
Foster, F. K., Wichita Falls, Tex.
Freedman, L. H., Fort Worth, Tex.
Frei, Frederick, Dallas, Tex.
Funk, Marion H., Ada, Okla.
Fuqua, H. B., Fort Worth, Tex.
Gahring, William R., Shawnee, Okla.
Galbraith, T. J., Alpine, Tex.
Gale, Hoyt S., Los Angeles, Calif.
Gardner, Julia, Washington, D. C.
Garlough, J. L., Wichita, Kan.
Garrett, Lovic P., Houston, Tex.
Garrett, Melvin M., Wichita Falls, Tex.
Garrett, Robert E., Tulsa, Okla.
Gester, George C., San Francisco, Calif.
Getzendaner, Frank M., Uvalde, Tex.
George, H. C., Norman, Okla.
Giffin, Wilson C., Los Angeles, Calif.
Giles, Albert W., Fayetteville, Ark.
Gillan, Silas L., Los Angeles, Calif.
Gish, Wesley G., Fort Worth, Tex.
Goldston, Walter L., Jr., Cisco, Tex.
Goodrich, Robert D., Fort Worth, Tex.
Gouin, Frank, Duncan, Okla.
Gould, Chas. N., Norman, Okla.
Grant, Paul A., Fort Worth, Tex.
Gray, Alfred, Carlsbad, N. M.
Gray, Allan B., San Angelo, Tex.
Green, Darsie A., Ardmore, Okla.
Green, Guy E., Midland, Tex.
Greene, Frank C., Tulsa, Okla.
Grimm, Maurice W., Shreveport, La.
Griswold, Clyde T., Albuquerque, N. M.
Grogan, Samuel A., Tampico, Mexico
Gulley, M. Gordon, Pittsburgh, Pa.

Hager, Dilworth, S., Lockhart, Tex.
Hagy, Lawrence R., Amarillo, Tex.
Hall, Roy H., Wichita, Kan.
Hamill, Chester A., Dallas, Tex.
Hamilton, W. R., Tulsa, Okla.
Hamm, W. Dow, Dallas, Tex.
Hammer, Alva A., Abilene, Kan.
Hanna, Marcus A., Houston, Tex.
Harnsberger, T. K., Tulsa, Okla.
Harper, Oliver C., Midland, Tex.
Harrison, Thomas S., Denver, Colo.
Hartley, Burton, Cisco, Tex.
Hartman, Adolph E., San Antonio, Tex.
Haseman, W. P., Oklahoma City, Okla.
Hawley, Henry J., San Francisco, Calif.
Hazzard, Roy T., Shreveport, La.
Heath, Francis E., Dallas, Tex.
Hedrick, O. F., Thurber, Tex.
Heiland, Carl A., Golden, Colo.
Henderson, H. H. San Angelo, Tex.
Hennen, Ray V., Tulsa, Okla.
Henning, John L., Lake Charles, La.
Henson, Gurrie R., Tulsa, Okla.
Herald, Frank A., Fort Worth, Tex.
Herald, J. M., Tulsa, Okla.
Heroy, Wm. B., White Plains, N. Y.
Hiestand, Thomas C., Tulsa, Okla.
Higgs, Morton T., Dallas, Tex.
Hill, Harry B., Dallas, Tex.
Hockman, James N., San Angelo, Tex.
Hoffman, Charles C., Fort Worth, Tex.
Hoffman, Malvin G., Tulsa, Okla.
Hoover, James E., Tulsa, Okla.
Hopper, Walter E., Shreveport, La.
Horkey, William E., Tulsa, Okla.
Horton, Leo V., Tulsa, Okla.
Hosterman, John F., San Angelo, Tex.
Housh, C. N., Houston, Tex.
Howard, William M., San Antonio, Tex.
Howard, W. V., Urbana, Ill.
Howe, Henry V., Baton Rouge, La.
Howell, Jesse V., Ponca City, Okla.
Howeth, Irving K., Houston, Tex.
Hoyle, Charles R., Shawnee, Okla.
Hoyt, William V., Cisco, Tex.
Hudnall, James S., Coleman, Tex.
Hudson, William A., Fort Worth, Tex.
Hughes, C. Don, Amarillo, Tex.
Hughes, Richard, Tulsa, Okla.
Hughes, Urban B., Wichita Falls, Tex.
Hull, Joseph P. D., Tulsa, Okla.
Hummel, E. W., Mountain View, Okla.
Hummel, H. L., Abilene, Tex.
Huntley, Louis G., Pittsburgh, Pa.
Hyde, Clarence E., Fort Worth, Tex.
Imbt, Robert F., San Angelo, Tex.
Irwin, J. S., Denver, Colo.
Israelsky, Merle C., Shreveport, La.
Ivy, John Smith, Shreveport, La.
Jablonski, Eugene, San Antonio, Tex.
Jay, Stanley E., San Angelo, Tex.
Jeffreys, Geoffrey, New York, N. Y.
Jennings, Charles I., San Angelo, Tex.
Jones, Alva V., Abilene, Tex.
Jones, Boone, Cushing, Okla.
Jones, Coy B., Abilene, Tex.
Jones, Edward L., San Angelo, Tex.
Johnson, J. Harlan, Golden, Colo.
Johnson, Roswell H., Pittsburgh, Pa.
Judson, Sidney A., Houston, Tex.
Justice, Philip S., Beaumont, Tex.
Kautz, Archie R., Wichita Falls, Tex.
Kay, Fred H., New York, N. Y.
Keeler, William W., Tulsa, Okla.
Keeley, L. C., Tampico, Mexico
Keith, Arthur, Washington, D. C.
Keller, P. Hastings, Duncan, Okla.
Kendrick, Frank E., Dallas, Tex.
Kennedy, John B., Oklahoma City, Okla.
Kent, Joseph T., Dallas, Tex.
Keppler, Leo G., Tulsa, Okla.
Kernan, Thomas H., Fort Worth, Tex.
Kesler, L. W., Wichita, Kan.
Keyte, I. A., Colorado Springs, Colo.
Kimball, E. B., Fort Worth, Tex.
King, Charles C., Tulsa, Okla.
Kirby, Grady C., San Antonio, Tex.
Kister, Herbert H., Enid, Okla.
Klinger, Edgar D., San Angelo, Tex.
Knappen, Russell S., Tulsa, Okla.
Kneale, William C., Carlsbad, N. M.
Knebel, G. Moses, Palestine, Tex.
Kniker, Hedwig T., San Angelo, Tex.
Kolm, Robert N., Abilene, Tex.
Kramer, William B., Ballinger, Tex.
Kraus, Edgar, San Angelo, Tex.
Kroenlein, George A., San Angelo, Tex.
Lahee, Frederic H., Dallas, Tex.
Laird, Lee, Dallas, Tex.
Lambert, Gerald S., Bartlesville, Okla.
Lang, W. B., Roswell, N. Mexico
Langworthy, A. A., Tulsa, Okla.
Laskey, G. E., Wichita Falls, Tex.
Lasky, Bernard H., Tulsa, Okla.
Laughlin, R. W., Wewoka, Okla.
Leach, Thos. W., Tulsa, Okla.
Lee, Marvin, Wichita, Kan.
Lee, Wallace, Okmulgee, Okla.
Levorsen, A. Irving, Tulsa, Okla.
Lewis, Frank E., San Angelo, Tex.
Lewis, J. Volney, New York, N. Y.
Lewis, J. Whitney, Fort Worth, Tex.
Liddle, Ralph A., Fort Worth, Tex.
Lieb, Victor E., Houston, Tex.
Lillibridge, Harry E., Enid, Okla.
Lilligren, J. M., Enid, Okla.
Lindeblad, E. E., Bartlesville, Okla.
Livingston, Noyes B., Fort Worth, Tex.
Lloyd, Abe M., Wichita Falls, Tex.
Lloyd, E. Russell, Midland, Tex.

Logan, Clarence Z., Tulsa, Okla.
Longyear, Robert D., Minneapolis, Minn.
Loomis, Harve, Abilene, Tex.
Lounsberry, D. E., San Angelo, Tex.
Lowman, Shepard W., Tulsa, Okla.
Lyle, William M., Fort Worth, Tex.
Lynn, Robert H., Amarillo, Tex.
Lyons, Richard T., Tulsa, Okla.
MacDonell, James A., Lima, Ohio
MacKay, Hugh, Sapulpa, Okla.
MacKay, Donald K., Dallas, Tex.
Markley, Elmer A., Tulsa, Okla.
Markham, Edmond O., Tulsa, Okla.
Martin, George C., Washington, D. C.
Mason, Shirley L., Pittsburgh, Pa.
Masterson, Reba B., San Antonio, Tex.
Matson, Geo. C., Tulsa, Okla.
Matson, Martin, Bartlesville, Okla.
McClellan, Hugh W., Bartlesville, Okla.
McCluer, R. D., San Angelo, Tex.
McCollough, E. H., Bakersfield, Calif.
McCoy, Alex W., Ponca City, Okla.
McCrary, E. W., Tulsa, Okla.
McDonald, Worth W., Shreveport, La.
McFarland, R. S., Tulsa, Okla.
McFerron, George I., Tulsa, Okla.
McLellan, Hiram J., Tyler, Tex.
McNutt, Vachel H., San Antonio, Tex.
McWhirt, Burr, Tulsa, Okla.
Meland, Norman, Oklahoma City, Okla.
Melcher, A. F., Tulsa, Okla.
Meredith, Carlton, Dallas, Tex.
Merritt, J. W., Tulsa, Okla.
Merry, Edward T., Fort Worth, Tex.
Metcalf, Roy J., Fort Worth, Tex.
Meyer, Arthur M., Ardmore, Okla.
Meyers, Percy A., Abilene, Tex.
Milek, Andrew, Tampico, Mexico
Miller, E. Floyd, Tulsa, Okla.
Miller, John C., Houston, Tex.
Miller, Willard L., Oklahoma City, Okla.
Miller, Wendell Z., Tulsa, Okla.
Mills, R. van A., Tulsa, Okla.
Minor, H. E., Houston, Tex.
Miser, Hugh D., Washington, D. C.
Mix, C. A., Carlsbad, N. M.
Mix, Sidney E., Shreveport, La.
Mohr, C. L., Bartlesville, Okla.
Moncrief, E. C., Wichita, Kan.
Monnett, V. E., Norman, Okla.
Moody, Graham B., Dallas, Tex.
Moody, Clarence L., Shreveport, La.
Moore, Hastings, Tulsa, Okla.
Moore, John I., San Angelo, Tex.
Moore, Prentiss D., Calgary, Alta, Can.
Moore, Raymond C., Lawrence, Kan.
Morgan, D. M., Ponca City, Okla.
Morgan, George D., Fort Worth, Tex.
Morero, Joseph E., Roswell, N. M.
Morley, Harold T., Abilene, Tex.
Mosburg, Lewis G., Shreveport, La.
Moulton, Gail F., Urbana, Ill.
Muir, John M., Dallas, Tex.
Munn, M. J., Tulsa, Okla.
Munroe, Donald J., Jackson, Miss.
Murphy, Earle N., Bristow, Okla.
Murphy, P. C., Houston, Tex.
Myers, John C., Houston, Tex.
Myers, Julian Q., Laredo, Tex.
Nelson, Jean O., Shreveport, La.
Neumann, L. Murray, Tulsa, Okla.
Nichols, C. R., Dallas, Tex.
Nicholls, William M., Wichita Falls, Tex.
Nickell, C. O., Wichita Falls, Tex.
Nisbet, John M., Bartlesville, Okla.
Noble, Earl B., Los Angeles, Calif.
Noble, Homer A., Houston, Tex.
Nolte, Wm. J., Wichita Falls, Tex.
Nordman, O. E., Tulsa, Okla.
North, Lloyd, Houston, Tex.
Norton, George H., Wichita, Kan.
Norville, Glen S., Ponca City, Okla.
Obering, Ernest A., Carlsbad, N. Mexico
Oborne, Harry W., Colorado Springs, Colo.
Oldham, Albert E., Tyler, Tex.
Olsson, Axel A., Gloversville, N. Y.
Ott, Emil, San Angelo, Tex.
Orynski, Leonard W., Dallas, Tex.
Owen, Edgar W., Eastland, Tex.
Owens, Frith C., Houston, Tex.
Packard, Sidney A., Shreveport, La.
Packard, Henry J., Denver, Colo.
Page, James H., Chanute, Kan.
Parker, Ben H., Tulsa, Okla.
Parrish, Gaston H., Corpus Christi, Tex.
Patrick, Walden W., Fort Worth, Tex.
Patterson, J. M., Tulsa, Okla.
Patton LeRoy T., Lubbock, Tex.
Paxson, Roland B., Houston, Tex.
Peabody, Harlan W., Tulsa, Okla.
Perini, Vincent C., Jr., Fort Worth, Tex.
Perrine, Irving, Oklahoma City, Okla.
Pellekaan, W. van Holst, St. Louis, Mo.
Pepperberg, Leon J., Columbus, Ohio
Peterson, Clarence J., Bartlesville, Okla.
Petsch, Arthur H., Saltillo, Coah., Mex.
Petree, L. W., Dallas, Tex.
Philbrick, E. P., Tulsa, Okla.
Pirtle, George W., Coleman, Tex.
Plummer, F. B., Austin, Tex.
Pogue, Joseph E., New York, N. Y.
Porch, Edwin L., Jr., San Antonio, Tex.
Potter, Grover C., Tulsa, Okla.
Poulsen, Frank E., Fort Worth, Tex.
Powell, Ralph S., Wichita Falls, Tex.
Powers, Sidney, Tulsa, Okla.
Pratt, Wallace E., Houston, Tex.
Preece, Rae, Tulsa, Okla.
Price, W. Armstrong, Houston, Tex.
Prout, F. S., Roswell, N. M.

Quilliam, William, Beaumont, Tex.
Radler, Dollie, Tulsa, Okla.
Rae, Colin C., Tulsa, Okla.
Rankin, Charles L., Shreveport, La.
Rath, Charles M., Denver, Colo.
Rau, Harold L., Seminole, Okla.
Reid, Robert P., Bartlesville, Okla.
Remington, Arthur E., San Angelo, Tex.
Renaud, Charles L., Abilene, Tex.
Renick, B. Coleman, Houston, Tex.
Rettger, Robert E., San Angelo, Tex.
Reynolds, Roy A., Fort Worth, Tex.
Reeside, John Bernard, Jr., Hyattsville, Md.
Reeves, Frank W., Dallas, Tex.
Rich, John L., Ottawa, Kan.
Richards, J. T., Shawnee, Okla.
Riggs, Robert J., Bartlesville, Okla.
Rixleben, Bruno, Tulsa, Okla.
Roberts, Louis C., Jr., Fort Worth, Tex.
Roberts, Morgan E., San Angelo, Tex.
Robertson, Parker A., Midland, Tex.
Robinson, Ernest Guy, Dallas, Tex.
Robinson, Heath M., Dallas, Tex.
Robinson, W. I., Lubbock, Tex.
Ross, John S., Shreveport, La.
Rothrock, Howard E., Tulsa, Okla.
Row, Charles H., San Antonio, Tex.
Rowley, Alden B., Tulsa, Okla.
Rusk, Willard W., Tulsa, Okla.
Russ, Leon F., Dallas, Tex.
Russell, P. G., Eastland, Tex.
Russell, William L., New Haven, Conn.
Rutledge, R. B., Wichita, Kan.
Ryan, Russell F., Houston, Tex.
Ryniker, Charles, Tulsa, Okla.
Sackett, H. F., Tulsa, Okla.
Sale, Clarence M., Norman, Okla.
Samuell, J. Howard, Coleman, Tex.
Sawyer, Roger W., Oklahoma City, Okla.
Sawtelle, George, Houston, Tex.
Schilling, Karl H., Dallas, Tex.
Schlosser, Paul A., Carlsbad, N. Mexico
Schneider, G. W., Shreveport, La.
Schneider, Henry G., Shreveport, La.
Schnurr, Cornelius, Oklahoma City, Okla.
Schoeneck, Philip S., Big Spring, Tex.
Scholl, Louis A., Jr., Houston, Tex.
Schoolfield, R. F., San Antonio, Tex.
Schramm, E. F., Lincoln, Neb.
Schwennesen, Alvin T., Houston, Tex.
Scholl, Guy J., Wichita Falls, Tex.
Scott, Gayle, Fort Worth, Tex.
Scott, Walter W., Houston, Tex.
Scudder, E. W., Denver, Colo.
Sealey, Fred C., Wichita Falls, Tex.
Seashore, Paul T., Houston, Tex.
Selig, A. L., Fort Worth, Tex.
Sellards, E. H., Austin, Tex.
Severy, C. L., Tulsa, Okla.
Shea, E. F., Tulsa, Okla.
Shelton, George H., Alpine, Tex.
Sheldon, Israel R., Wichita Falls, Tex.
Shutt, Roscoe E., St. Louis, Mo.
Shuler, Ellis W., Dallas, Tex.
Sickler, Jack M., Los Angeles, Calif.
Singewald, Quentin D., Golden, Colo.
Siverson, G. C., Tulsa, Okla.
Snow, Dale R., Tulsa, Okla.
Smiley, H. F., Wichita Falls, Tex.
Smith, Walter R., Corsicana, Tex.
Snider, L. C., New York, N. Y.
Snyder, John Y., Shreveport, La.
Somers, Ransom E., Pittsburgh, Pa.
Spofford, Howard N., Shreveport, La.
Spooner, W. C., Shreveport, La.
Stacy, Dean M., Oklahoma City, Okla.
Stathers, Silas C., Shreveport, La.
St. Clair, Stuart, New York, N. Y.
St. Germain, R. J., Tulsa, Okla.
Stearn, Noel H., St. Louis, Mo.
Steiner, George, New York, N. Y.
Steinmayer, R. A., New Orleans, La.
Stephenson, L. W., Washington, D. C.
Stevens, George R., Shreveport, La.
Stewart, Hugh A., Denver, Colo.
Stiles, Elisabeth, Houston, Tex.
Stiles, Edmund B., Fort Worth, Tex.
Storm, Lynn W., Austin, Tex.
Storm, Willis, Tulsa, Okla.
Studt, Charles W., Independence, Kan.
Tarr, W. A., Columbia, Mo.
Tatum, James L., Laredo, Tex.
Taylor, Charles H., Oklahoma City, Okla.
Teas, L. P., Houston, Tex.
Teas, Paul C., Colorado, Tex.
Terrill, J. V., Amarillo, Tex.
Thom, W. T., Jr., Princeton, N. J.
Thomas, C. R., Eldorado, Kan.
Thomas, George Dewey, St. Louis, Mo.
Thomas, J. Elmer, Fort Worth, Tex.
Thomas, Norman L., Fort Worth, Tex.
Thompson, B. E., Fort Worth, Tex.
Thompson, Charles L., Eastland, Tex.
Thompson, James D., Jr., Fort Worth, Tex.
Thompson, R. R., Fort Worth, Tex.
Thompson, T. C., Abilene, Tex.
Thompson, Wallace C., Wichita Falls, Tex.
Thornburg, D. H., Dallas, Tex.
Thornburgh, H. R., Midland, Tex.
Tomlinson, Charles W., Ardmore, Okla.
Trager, Earl A., Tulsa, Okla.
Trask, Parker D., Stanford University, Calif.
Trout, L. E., Wichita Falls, Tex.
Trowbridge, Arthur C., Iowa City, Iowa
Troxell, John N., Tulsa, Okla.
Truex, Arthur F., Tulsa, Okla.

Tygrett, H. V., Dallas, Tex.
Tyson, Alfred K., San Antonio, Tex.
Umpleby, Joseph B., Norman, Okla.
Vance, Warner R., Midland, Tex.
Van Dall, John E., Covington, Okla.
van Weelden, Arie, Dallas, Tex.
Vorbe, Georges, Midland, Tex.
Vernon, I. J., Anadarko, Okla.
Vertrees, Charles D., Abilene, Tex.
Vetter, John M., Houston, Tex.
Wagener, Charles H., San Antonio, Tex.
Walker, W. L., Bartlesville, Okla.
Wallingford, J. K., Abilene, Tex.
Waring, Gerald A., Tulsa, Okla.
Wasson, Harold J., New York, N. Y.
Wasson, Theron, Chicago, Ill.
Waters, James A., Dallas, Tex.
Watson, Joseph D., Tulsa, Okla.
Watson, C. P., Fort Worth, Tex.
Weaver, Paul, Houston, Tex.
Wegemann, Carrol H., New York, N. Y.
Weinzierl, John F., Houston, Tex.
Weirich, T. E., Tulsa, Okla.
Wells, Lloyd E., Wichita Falls, Tex.
Welsh, LeRoy G., Abilene, Tex.
Wender, W. G., Cisco, Tex.
Wendlandt, E. A., Tyler, Tex.
Westby, Gerald H., Bartlesville, Okla.
Weeks, Albert W., San Antonio, Tex.
Whisenant, John B., Big Springs, Tex.
White, Maynard P., Ardmore, Okla.
White, Luther H., Tulsa, Okla.
White, Stanley B., Fairview, Okla.
Whittier, William H., San Angelo, Tex.
Whitney, F. L., Austin, Tex.
Whitwell, E. V., Jackson, Miss.
Wilson, Edward B., San Angelo, Tex.
Wilson, Malcolm E., Shreveport, La.
Wilson, John H., Golden, Colo.
Wilson, Joseph M., Dallas, Tex.
Wilson, Walter B., Tulsa, Okla.
Williams, Herbert E., Abilene, Tex.
Williston, Samuel H., Dallas, Tex.
Willis, S. Morse, Tulsa, Okla.
Willis, Robin, Midland, Tex.
Winter, Niles B., Pecos, Tex.
Winton, Will M., Fort Worth, Tex.
Woods, Sam H., Ardmore, Okla.
Woolsey, E. V., Dallas, Tex.
Wrather, William E., Dallas, Tex.
Wright, Andrew C., Coleman, Tex.
Wright, Fred S., Fort Stockton, Tex.
Yager, Charles E., Fort Worth, Tex.
Yewell, P. R., San Angelo, Tex.
Yoakam, Coler A., Tulsa, Okla.
Zavoico, Basil B., Tulsa, Okla.

ASSOCIATE

Abbott, John L., San Angelo, Tex.
Aldridge, Mort B., Tulsa, Okla.
Anderson, Lyman P., Ardmore, Okla.
Anderson, W. D., Midland, Tex.
Arick, Millard B., Austin, Tex.
Ballard, Andrew L., San Antonio, Tex.
Ballard, James L., Denver, Colo.
Barling, Robert, Midland, Tex.
Barrett, Morris K., San Angelo, Tex.
Bartle, Ronald L., Bloomington, Ind.
Bartlett, C. Lothrop, Dallas, Tex.
Bauernschmidt, A. J., Jr., Dallas, Tex.
Beilharz, Carl F., El Dorado, Ark.
Benedum, Darwin, San Antonio, Tex.
Bingham, D. H., Corsicana, Tex.
Blackburn, Willis C., Houston, Tex.
Bohart, Morris F., Fort Worth, Tex.
Bornhauser, Max, Dallas, Tex.
Bradley, Everett L., Amarillo, Tex.
Brant, Ralph A., Tulsa, Okla.
Brewer, Charles, Jr., Bartlesville, Okla.
Brian, J. Carl, Aspermont, Tex.
Brice, John W., McCamey, Tex.
Buckstaff, Sherwood, Chickasha, Okla.
Bunte, Arnold S., Rankin, Tex.
Carpenter, Margaret C., Fort Worth, Tex.
Carsey, J. Ben, McCamey, Tex.
Cartwright, Lon D., Jr., Midland, Tex.
Cash, Thornton C., Corsicana, Tex.
Cassingham, Robert L., Enid, Okla.
Chapman, Guy E., Fort Worth, Tex.
Chatman, Cecil L., McCamey, Tex.
Cheney, Robert B., Wickett, Tex.
Christner, J. B., Austin, Tex.
Clark, John W., Merion Station, Pa.
Clifford, O. C., Jr., Bartlesville, Okla.
Cooper, Chalmer L., Norman, Okla.
Copass, Jack M., Shawnee, Okla.
Coulson, Harry S., Boulder, Colo.
Cox, Thomas S., Aspermont, Tex.
Crandall, Kenneth H., Carlsbad, N. Mexico
Curry, William H., Jr., San Antonio, Tex.
Davis, Morgan J., Roswell, N. Mexico
Decker, LaVerne, Cisco, Tex.
DeFord, Ronald K., Roswell, N. Mexico
Denning, Wayne H., Golden, Colo.
Dicken, Russell H., Duncan, Okla.
Dickson, Hugh, Tulsa, Okla.
Donahue, Frank, Midland, Tex.
Douglas, O. Hubert, Jr., Okmulgee, Okla.
Durward, Robert Harland, Wichita Falls, Tex.
Ekholm, Victor E., Coleman, Tex.
Estergren, E. F., Fort Worth, Tex.
Evans, Frank G., Jr., Tyler, Tex.
Fergus, Preston, Monroe, La.
Field, Walter S., Wichita, Kan.
Fitts, John, Ada, Okla.

Fitzgerald, James, Jr., Eldorado, Kan.
Francis, George A., San Angelo, Tex.
Frazier, Gaylord G., Russell, Kan.
Fritts, Harold M., San Angelo, Tex.
Funk, Fred J., Fort Worth, Tex.
Gallagher, William G., Abilene, Tex.
Germany, E. B., Dallas, Tex.
Giddings, Harvard, Eastland, Tex.
Gierhart, Guy B., Laredo, Tex.
Gibbs, James F., Wichita Falls, Tex.
Gould, Don B., Winfield, Kan.
Gray, Shapleigh G., Fort Worth, Tex.
Grigsby, G. O., Shreveport, La.
Grinsfelder, Sam, Abilene, Tex.
Haase, Fred M., Shreveport, La.
Hall, Ellis, San Angelo, Tex.
Hanson, Perry R., Wichita, Kan.
Hanson, Edwin V., Houston, Tex.
Harlton, Bruce H., Tulsa, Okla.
Harrell, David C., San Angelo, Tex.
Harrell, Marshall A., Dallas, Tex.
Harris, Edwin S., Henderson, Tex.
Harris, R. W., Norman, Okla.
Harvey, William W., Midland, Tex.
Hawkins, I. M., Dallas, Tex.
Hawtof, E. Manuel, Wickett, Tex.
Hedley, J. David, Amarillo, Tex.
Hoover, J. Wilkinson, Carlsbad, N. Mexico
Hoover, William B., Amarillo, Tex.
Hoskins, Baker, Jr., Laredo, Tex.
Huddleston, Arthur N., San Angelo, Tex.
Hupp, John Ervin, Casper, Wyo.
Ilsley, Ralph, San Angelo, Tex.
Ingham, W. I., Golden, Colo.
Imholz, Harry W., Abilene, Tex.
Jeffrey, H. C., Abilene, Tex.
Jenny, W. P., Houston, Tex.
Jones, Roy D., Okmulgee, Okla.
Johnson, T. J., Abilene, Tex.
Kamb, Hugo R., Allen, Okla.
Kauenhowen, Walter, Shreveport, La.
Keller, Paul L., San Angelo, Tex.
Kelly, Donald, Wichita Falls, Tex.
Kelly, Pennell C., Fort Stockton, Tex.
Kemp, Augusta Hasslock, Seymour, Tex.
Keyes, Wilson, San Angelo, Tex.
Kisling, James W., Jr., Shreveport, La.
Kornfeld, M. M., Houston, Tex.
Lake, Charles L., Temple, Tex.
Lamb, R. C., Cisco, Tex.
LaRue, James E., Houston, Tex.
Lee, Huylar W., Cisco, Tex.
Lincoln, B. W., Chickasha, Okla.
Longnecker, Oscar M., Jr., Houston, Tex.
Loskamp, Alvin P., Midland, Tex.
Lovejoy, J. B., Wichita Falls, Tex.
Lund, Gage V., Denver, Colo.
MacNaughton, Lewis W., Midland, Tex.
Magalis, Cyrus W., Dallas, Tex.
Manion, Clarence E., Fort Collins, Colo.
Maley, Vaughn C., McCamey, Tex.
Markley, Joseph H., Jr., Wichita Falls, Tex.
Mathes, Donald E., Dallas, Tex.
Maucini, Joseph J., Amarillo, Tex.
McCarter, W. Blair, Beeville, Tex.
McCollom, Leonard F., San Antonio, Tex.
McFarland, Paul W., San Antonio, Tex.
McKague, Bruce C., Fort Worth, Tex.
McLaughlin, Homer C., Duncan, Okla.
McMillen, Raymond F., Tulsa, Okla.
Milner, Charles A., Jr., Ardmore, Okla.
Mills, Coe S., Fort Worth, Tex.
Moreman, W. L., Lawrence, Kan.
Morris, Walter W., Henryetta, Okla.
Morrison, T. E., Houston, Tex.
Morse, Paul F., Houston, Tex.
Mower, Lowell K., Dallas, Tex.
Moyse, Nathan I., Tulsa, Okla.
Muldrow, Robert, Jr., Midland, Tex.
Munson, Herbert E., Pittsburg, Kan.
Nance, Albert G., Fort Worth, Tex.
Norton, Richard D., Shreveport, La.
Oles, L. M., Amarillo, Tex.
Oles, Paul S., Wichita Falls, Tex.
Oliphant, A. G., Tulsa, Okla.
Oyster, Frank A., Abilene, Tex.
Pack, Oran L., Abilene, Tex.
Parsons, Claude P., Cyril, Okla.
Pepper, James F., Geneva, N. Y.
Pettigrew, Virgil, Wichita Falls, Tex.
Phillips, E. Douglas, Baton Rouge, La.
Pishney, Charles H., Tulsa, Okla.
Ports, Waldo W., Wichita Falls, Tex.
Potter, Nelson B., Chickasha, Okla.
Quiett, Roy C., Seminole, Okla.
Rauch, Wayne C., Dallas, Tex.
Redfield, John S., Norman, Okla.
Reed, Lyman C., Houston, Tex.
Rice, Elmer M., Fort Worth, Tex.
Richards, A. Howard, Oklahoma City, Okla.
Ridgeway, Bertrand S., Independence, Kan.
Rife, Byron, Abilene, Tex.
Rogatz, Henry, Amarillo, Tex.
Rolshausen, F. W., Houston, Tex.
Rossebo, C. B., Tulsa, Okla.
Ryan, Reginald G., Graham, Tex.
Sappington, Chester, Ardmore, Okla.
Sayre, J. E., Shawnee, Okla.
Schaeffer, Hugh C., Oklahoma City, Okla.
Schmidt, Karl A., Fort Worth, Tex.
Schwarz, Melbert E., Houston, Tex.
Schweer, Harry F., Chickasha, Okla.
Seaman, L. O., Abilene, Tex.
Seevers, H. H., Wichita Falls, Tex.
Seitz, J. R., Wichita Falls, Tex.
Self, Selden R., San Angelo, Tex.

Sidwell, Raymond, Lubbock, Tex.
Skirvin, Orren W., Ada, Okla.
Smith, A. J., Tulsa, Okla.
Smith, Robert H., Wickett, Tex.
Spaulding, Ralph V., Tulsa, Okla.
Sprague, William B., Houston, Tex.
Stangle, Frank J., Jr., Fort Worth, Tex.
Stastny, H. R., Graham, Tex.
Stein, Ira H., Ponca City, Okla.
Stewart, Charles A., San Antonio, Tex.
Stewart, Robert J. G., Carlsbad, N. Mexico
Swiger, Rual B., San Antonio, Tex.
Tatum, E. P., Jr., Houston, Tex.
Tims, Vergil E., Wichita Falls, Tex.
Toler, Henry N., Urbana, Ills.
Tollefson, E. H., Wichita Falls, Tex.
Upson, M. E., Fort Worth, Tex.
Vanderpool, Harold C., Houston, Tex.
Van Zant, James H., Enid, Okla.
Vernon, Jess, Shawnee, Okla.
Vickery, Ward R., Blackwell, Okla.
Wagner, Clyde L., Tulsa, Okla.
Wagoner, George E., Golden, Colo.
Watson, W. Verde, Roswell, N. Mexico
Welch, Virgil H., Shawnee, Okla.
Weed, W. F., Beaumont, Tex.
Weeks, Herbert J., Dallas, Tex.
Wheeler, Carlton W., Ardmore, Okla.
Wheeler, Holmes Cubbage, Colorado, Tex.
Whitcomb, Bruce, Fort Worth, Tex.
Wilson, Homer M., Del Rio, Tex.
Wimbish, Forrest E., Tulsa, Okla.
Woods, E. Hazen, Big Spring, Tex.
Woolley, Glen C., Abilene, Tex.
Wyman, Everett A., San Angelo, Tex.
Wynn, Warren H., Shawnee, Okla.
Young, Karl Etienne, Houston, Tex.

FOURTEENTH ANNUAL BUSINESS MEETING
THE TEXAS HOTEL, FORT WORTH, TEXAS
MARCH 23, 1929

R. S. McFarland, *presiding*

President McFarland called the meeting to order at 10 A. M.

Minutes of the thirteenth annual meeting were not read, by unanimous consent.

Report of the President

The splendid attendance which we have at this, our fourteenth annual convention, is representative of the loyal and whole-hearted support that our members give to their profession and to this Association. The spirit of loyalty and good fellowship so manifest here is characteristic of our organization and has always been evident since its beginning. In former years the affairs of the Association were conducted largely by the voluntary services of the officers, who gave their time and services unselfishly. We have now grown to such a size that the affairs of the Association, to be conducted efficiently, require the full time of several permanently employed individuals. The Association, as now established, affords the officers an opportunity to give time and thought to the more important administrative problems of the Association as well as to study the ways and means of improving the efficiency of the organization and to determine how it can be of most service to the membership. Following our last annual meeting, the present executive committee took charge of an organization that was being successfully operated, was continually growing, and receiving the enthusiastic support of its members. We have concentrated our efforts in guiding it in the course upon which it was already directed and attempting, here and there, to make improvements.

The American Petroleum Institute, in 1927, after a thorough investigation by appointed committees, reported that the field of petroleum geology was being adequately provided for by the American Association of Petroleum Geologists. It is our duty to see that the Association keeps pace with the progress in the oil industry and continues to provide adequately for the field of petroleum geology and its allied interests.

The executive committee held three meetings at the Association office in Tulsa during the year and the important results of these meetings have been published in the *Bulletin*. In the business committee's report will be included a résumé of the recommendations of the executive committee, business representatives, and individual members. It is my intention to review very briefly the important activities of the past year and also to point out what, in my mind, are important unfinished activities that should be given careful thought and attention in the future.

The executive committee during the past year has, at every opportunity, tried to establish a closer contact with the membership and acquaint it with the important problems of the Association. The best medium for this was through the various local geological societies, and practically all of these societies have been visited during the year by some member of the committee. On behalf of the executive committee I desire to express to all of these societies our sincere appreciation of the loyal support and hearty welcome extended to us.

Membership.—The membership at the present time consists of 2,126 (1,952 last year) members scattered in 40 states and 30 foreign countries. During the past year our net increase in membership was 174 and we now have 170 applications (194 last year) under consideration. It has not been our intention in any way to make a concentrated effort to increase the membership. It is a remarkably healthy condition for the Association that last year only 62 members failed to pay their dues. Considering the number of specialized branches in the oil industry to-day, petroleum geology, *per se*, has probably reached a saturation point. The Association has reached such a size that it is not necessary to continue canvassing for new members, but at the same time we should always be on the lookout for high-class members of our profession who are eligible for membership.

Finances.—In the March number of the *Bulletin* a complete audit and inventory for the calendar year 1928 was printed. This audit is much more complete and comprehensive than has ever before been made, and reflects a very favorable financial condition for the year, as will be reported by David Donoghue, second vice-president in charge of finances. Heretofore the audit has consisted of a verification of the cash receipts and disbursements only, but in the audit this year, a balance sheet and a profit-and-loss account have been established and the actual assets and liabilities of the Association have been listed, including an inventory of printed matter on hand, as well as the income and expenses properly applicable to the year 1928. Our books of account have been arranged to reflect this condition in the future. The executive committee is anxious that this newly established system of auditing shall be continued from year to year. A large fire-proof safe was purchased to hold all of the valuable books and records of the Association. An escrow agreement account was

established with the Exchange Trust Company at Tulsa for the safe-keeping and investment of our permanent funds. Under this agreement, for a nominal charge, this trust company is custodian of our securities, clips the coupons, watches maturity dates, and makes recommendations for changes and the investment of new funds. All new investments are subject to the approval of the executive committee and the account can be withdrawn at any time.

Publications.—The executive committee last year arranged for the publication of the *Bulletin* in Tulsa. This proved to be a very judicious and satisfactory move. Every effort has been made to continue the same high standards which have always been maintained in this publication. We are now publishing 3,000 copies each month. There were not so many descriptive papers in the *Bulletin* this year as usual due to the fact that most of this type of material was reserved for special publication. You have all, by this time, seen a copy of Volume I of *Structure of Typical American Oil Fields.* Already 570 copies of this book have been sold. Volume II is now being prepared for publication and will be available the latter part of the year. The Association owes a great debt of gratitude to Sidney Powers for his untiring efforts, both in arranging the program which provided material for these volumes, and in helping to get them into print. Mr. Hull and his associates are to be highly commended for the splendid manner in which they have continued the editorial work, both in the *Bulletin* and in the special publications.

Research.—A new research committee, with definite term of office, was appointed during the year, under the chairmanship of A. W. McCoy. This committee has given considerable thought to the establishment of a permanent research bureau or organization within the Association, and will make its report at this meeting. You are all familiar with the Permo-Carboniferous research project which was initiated by the Society of Economic Paleontologists and Mineralogists and which is now an official project of the Association under the research committee, directed by Raymond C. Moore as general chairman. Although less than a year old, this project has made wonderful progress. Dr. Condra as state chairman for Nebraska has contributed liberally. Fred Plummer as state chairman for Texas has been very active and the first results of his efforts are on exhibit here at this meeting. This is a very commendable and practical form of research work, which the Association can heartily sponsor, and it is hoped every effort will be made to continue it.

Technical and regional sections.—The Association has grown to such a size and the science of petroleum geology has developed into so many specialized groups that it is important for the parent organization to foster and correlate these specialized groups that they may be adequately provided for, that each may function most efficiently, that duplication of work, publication, or interest of any kind may be avoided, and that the activities of these specialized groups shall not at any time in the future work to the disadvantage of the parent organization or encroach upon its proper function. In order to accomplish this it is very important that these groups form themselves into technical sections of the Association.

Endowment.—Almost every problem of the Association involves two important features, organization and finance. Organization is of primary importance not only in improving the business efficiency of our headquarters office,

enlarging the work in order to provide for the specialized groups and technical sections, but also in our research work. The American Petroleum Institute has the finances and personnel to conduct research of the expensive type such as is being carried on at present. However, there are many types of research, such as the Permo-Carboniferous project, and study of the structure of oil fields suggested by A. W. McCoy, which will probably never be attempted by the American Petroleum Institute and which rightfully should be conducted by the American Association of Petroleum Geologists.

Research to be effective must be spontaneous, and it is this voluntary research which is most productive. Very little can be accomplished, however, even in this type of research, unless we have a small amount of money to spend. The first effort to raise funds among the members of the Association was in 1925, when 23 individuals, through the efforts of W. E. Wrather, chairman of the research committee, subscribed approximately $8,000 for research work. Most of this money was spent for the prosecution of specific projects with which you are all familiar. A portion of this fund is still available and is now being used by the research committee.

Our present financial condition will enable us to provide adequately for our headquarters office as well as one or two technical sections. During the past five or six years the raising of an endowment fund has been suggested many times, but nothing very definite has been accomplished. Conditions in the oil business at the present time are not sufficiently favorable to justify our attempting to raise a large endowment fund, but I do think the Association should go ahead and raise, within its membership, but not through the oil companies, enough money to provide for the present inexpensive forms of research work that are contemplated. Several methods have been suggested by which to raise money to carry on this research. My idea would be to have this meeting authorize the executive committee to be responsible for the raising of funds, and the executive committee in turn could work out the most feasible plan and appoint what assistance they need. It has been suggested that every year when the dues are mailed out, each member might voluntarily contribute $1.00 to research. If all the members would contribute in this way, the resulting fund would practically be equivalent to the income from $50,000.

We are now in a position to increase our permanent investment fund to at least $25,000 and, provided we do not have to use any of this money for research work, it probably could be increased gradually from year to year. Yet we have many members in our Association who are willing to do research work and we certainly should back them up with sufficient funds to carry on the projects outlined.

In closing, let me take this opportunity to express my appreciation to the entire membership for their loyal support, which has made it a great pleasure for me to serve you as president. I desire especially to express my appreciation for the whole-hearted coöperation that has been given by the members of the executive committee, the general business committee, and also the Fort Worth committee whose untiring efforts have made this convention such an outstanding success.

R. S. McFarland

Second vice-president Donoghue, in charge of finances, presented his annual report.

REPORT ON MEMBERSHIP

The list of members as of March 1, 1929, has been published in the March *Bulletin*. During the past year, we have lost by death eight members, namely: T. C. Sherwood, Jr., Frank M. Smith, Carl W. Clarke, Laura L. Weinzierl, Julius Segall, Edwin Binney, Jr., Jean C. Thompson, and Jack J. King.

Our total membership is 2,126.

Membership of the Association:

Number of members May 19, 1917 (first published list)		94
Number of members February 15, 1918		176
Number of members March 15, 1919		210
Number of members March 18, 1920		392
Number of members March 15, 1921		621
Number of members March 8, 1922		767
Number of members March 20, 1923		901
Number of members March 20, 1924		1,080
Number of members March 21, 1925		1,253
Number of members March 20, 1926		1,504
Number of members March 1, 1927		1,670
Number of members March 1, 1928		1,952
Number of honorary members March 1, 1929	6	
Number of active members March 1, 1929	1,496	
Number of associate members March 1, 1929	624	
Total number of members, March 1, 1929		2,126
Increase in membership since March 1, 1928		174
Applicants elected, dues unpaid	44	
Applicants approved for publication	60	
Recent applications	66	
Total applications on hand		170
Applications for transfer approved, dues unpaid	23	
Applications for transfer approved for publication	54	
Recent applications for transfer	17	
Total applications for transfer on hand		94
Number of members withdrawn	16	
Number of members dropped	33	
Number of members died	8	
Total loss in membership		57
Number of members in arrears, 1928-29 dues	62	
Active members in arrears, 1929 dues	474	
Associate members in arrears, 1929 dues	247	
Total number of members in arrears, 1929 dues		721

Circulation of the Bulletin:

1. Subscriptions (non-members)		
Libraries (domestic, 106; foreign, 23)	129	
Companies (domestic, 37; foreign, 34)	71	
Individuals (domestic, 33; foreign, 26)	66	
Total non-member subscribers		266
2. Exchanges, etc.		73
3. Association members		2,126
Total monthly circulation of *Bulletin*		2,465

Geographic Distribution of A. A. P. G. Members:

UNITED STATES

Texas	591	West Virginia	6
Oklahoma	472	Iowa	5
California	285	Mississippi	5
Kansas	87	Montana	5
New York	79	Virginia	5
Colorado	67	Washington	5
Louisiana	60	Alabama	4
Pennsylvania	46	Nebraska	4
Illinois	28	Indiana	3
Missouri	24	Maryland	3
New Mexico	24	Oregon	2
District of Columbia	19	Tennessee	2
Ohio	13	Utah	2
Kentucky	12	Wisconsin	2
Wyoming	11	Arizona	1
Arkansas	9	Florida	1
Michigan	8	Georgia	1
Minnesota	7	Nevada	1
Connecticut	6	South Dakota	1
Massachusetts	6		
New Jersey	6	Total United States	1,918

FOREIGN

Venezuela	49	Germany	2
Mexico	41	Russia	2
Canada	16	Angola	1
Colombia	12	Belgian Congo	1
Argentina	10	Belgium	1
England	9	British Somaliland	1
Holland	9	Chile	1
Dutch East Indies	8	Ecuador	1
Roumania	6	Egypt	1
Switzerland	5	India	1
Japan	4	New Zealand	1
Peru	4	Nova Scotia	1
Austria	3	Scotland	1
France	3	South Africa	1
Trinidad	3		
Australia	2	Total Foreign	200

Address unknown	8
Grand Total	2,126

DAVID DONOGHUE, *2d vice-president*

Report on Finances

The financial condition of the Association is set forth in audit for the calendar year of 1928 as published in the March *Bulletin*. That statement shows a net "profit" of $9,273.46, which has since been used, partly to pay for the manufacture of *Structure of Typical American Oil Fields*, and partly to purchase bonds yielding interest for the maintenance of headquarters and the publication of scientific papers.

The present condition of the treasury is shown approximately by the following figures as of March 14, 1929.

GENERAL EXPENSE FUND		
Checking account	$ 5,159.86	
Interest-bearing account	10,000.00	
Total current funds available		$15,159.86
INVESTMENT FUND		
Interest-bearing bonds		28,133.75
PUBLICATION FUND		
Checking account	$ 2,322.09	
Interest-bearing account	1,937.39	
Total publication funds available		4,259.48
RESEARCH FUND		
Interest-bearing account		190.00
Total funds on hand		$47,743.09

On March 1, 1928, the total funds on hand amounted to $38,813.86; on March 10, 1927, the corresponding sum was $29,810.54. These figures indicate the continued growth of the Association. They also indicate our increasing ability for greater accomplishment. This year we are publishing more pages of petroleum geology than ever before. The two volumes of *Structure of Typical American Oil Fields* contain nearly 1,000 pages of new matter in addition to *Bulletin* publication. Our contributions to special phases of geology and to fundamental research in petroleum geology are increasing each year. It is evident, therefore, that the greater our resources, the greater our ability to accomplish results.

David Donoghue, *2d vice-president*

Because of the illness of 3d vice-president Rich, the editorial report was read by past president Gester.

Report on Editorial Work

There is very little of routine nature to be reported.

The *Bulletin* has been continued essentially unchanged during the past year.

The big thing out of the ordinary during that period in the way of publications has been the preparation of the two symposium volumes, *Structure of Typical American Oil Fields*. To Sidney Powers belongs the credit for pushing this work through to completion, and to Mr. Hull and his staff for the details of editing and preparation of the manuscripts for the press. The Association is deeply indebted to Mr. Powers for what I believe is one of the most useful contributions to petroleum geology ever published. Volume I is already available. Volume II is now in press and will be issued shortly.

I fear the membership of the A. A. P. G. is unduly bashful. During the three years I have held office, the membership has been increased by over 500, or more than 25 per cent, yet the number of papers submitted for publication in the *Bulletin* has not increased in anything like this proportion. In making this statement, I am aware, of course, that much of the energy which might otherwise have gone into *Bulletin* contributions has gone into papers for the two symposium volumes. But I still feel that the members are losing a valuable opportunity by failing to make use of the *Bulletin* more freely in reporting facts and expressing ideas which come to them in their work.

The field men particularly have unrivalled opportunity to observe interesting and important geologic phenomena, a record of which should be preserved. The *Bulletin* exists for this purpose.

Write out your contributions. Send them in. Don't be hurt if the editor asks you to revise them, for most papers have to undergo more or less revision. Only in this way can our Association and the *Bulletin* best serve its purpose.

JOHN L. RICH, *3rd vice-president*

W. E. Wrather read the report of the resolutions committee.

REPORT OF THE RESOLUTIONS COMMITTEE

Be it resolved, that the members of this Association, their wives, and guests, who have attended the Fort Worth meeting, most heartily appreciate the efficient and cordial coöperation rendered by the citizens of Fort Worth in making the fourteenth annual convention such an outstanding success.

Being fully cognizant of the many difficulties attendant upon satisfactorily housing and entertaining a gathering of the present proportions, they desire to express their sincere appreciation to all those who have contributed so effectively and unselfishly, both of time and of money, to this most pleasurable and profitable occasion.

It being manifestly impossible to mention specifically all those to whom thanks are due, it is desired nevertheless to offer sincere thanks

1. To the Fort Worth Chamber of Commerce,
2. To the several hotels of the city which have with patience and courtesy ministered to the comfort and convenience of guests,
3. To resident members of the Fort Worth Geological Society who have faithfully upheld the high standards, as to both program and arrangements, which have prevailed at past meetings,
4. To the host of individuals who aided in staging the rodeo and barbecue, in a manner to do credit to the best traditions of the city,
5. And lastly, to the host of friends for individual and group entertainments too numerous to mention.

Be it resolved, that these resolutions be spread on the minutes of this meeting and the secretary instructed to send copies to interested parties.

Be it resolved, that this Association extend to Dr. Charles P. Berkey of Columbia University its cordial thanks for the most interesting lecture on his travels in the Gobi Desert, and express to him the wish that this may be only the beginning of a pleasant association in the future.

Be it resolved, that this Association notes with regret the absence from this meeting of one of its loyal and enthusiastic members, R. B. Whitehead, who is seriously ill, and that he be appraised of the sincere wish of his associates for his speedy recovery.

W. E. Wrather, *chairman*
Earl B. Noble
Leon J. Pepperberg

The resolutions were unanimously adopted.

President McFarland requested Max W. Ball, chairman of the general business committee, to preside and present the recommendations for action of the Association.

Report of the Business Committee

In presenting the report of the committee, Mr. Ball offered the following motions:

1. *Term of officers*

Moved, that the executive committee hereby be instructed to prepare, and submit to letter ballot, the following

Amendment to the constitution:

That Article IV, Section 5, be amended to read: "The officers shall assume the duties of their respective offices immediately after the annual meetings in which they are elected."

The motion carried, with one opposed.

2. *Method of election*

Inasmuch as the master committee, Alexander Deussen, *chairman*, appointed by the president to study methods of electing officers, reports that a canvass of the membership shows a large majority in favor of retaining the present system, therefore, be it

Moved, that the present system of nomination and election be retained for at least another two years, at the end of which time, if there is then a strong sentiment in favor of a change, the president shall appoint another committee to study the subject further.

The motion carried unanimously.

3. *Membership in sections*

Moved, that the executive committee hereby be instructed to prepare and submit to letter ballot the following

Amendment to the constitution:

That Article VIII, Section 1, be amended by adding thereto the following words: "and such sections, with the approval of the executive committee, may

admit as affiliated members of the sections persons who are not fully qualified for active or associate membership in the Association, subject to the restrictions provided for associate members in the Constitution and such further restrictions as may be provided by the executive committee."

The motion carried, with three opposed.

4. *Expense of conventions*

Moved, that the executive committee is hereby authorized and empowered, whenever it shall deem such action necessary or expedient, to fix and collect, for any meeting of the Association, a registration fee intended to defray any part or all of the expense of the meeting.

The motion carried unanimously.

5. *Research*

Alex W. McCoy,[1] chairman of the research committee, presented a plan for encouraging fundamental research in petroleum geology.

Moved, that the Association desires to continue and expand its research work, and to this end the executive committee is hereby authorized and empowered to raise funds from the membership by such forms of voluntary subscription as to it seem wise.

The motion carried, with one opposed.

6. *District representatives*

Moved, that Section 5 of the by-laws be replaced by two new sections as follows:

Section 5. The executive committee shall from time to time designate and define districts and shall determine, according to the number of active members residing in each such district, the number of representatives to which it is entitled, and the active members in each such district shall choose, in such manner as to them seems best, the number of representatives to which the district is entitled. The terms of all district representatives hereafter elected shall be two years, and shall expire at the same time as the terms of officers.

Section 6. There shall be a business committee to act as a council and advisory board to the executive committee and the Association. This committee shall be made up of the executive committee, not more than five members at large appointed by the president, two members elected by and from each technical section, and the district representatives. The president shall also appoint a chairman from within or without the number of those theretofore chosen for the committee. If a district or technical representative is unable to be present at any meeting of the committee he may designate an alternate, who, in the case of a district representative, may or may not be a resident of the district he is asked to represent, and the alternate, on presentation of such a designation in writing, shall have the same powers and privileges as a regularly chosen representative.

The motion carried unanimously.

The business committee, MAX W. BALL, *chairman*
MARVIN LEE, *secretary*

[1]Mr. McCoy's report will be published later in the *Bulletin*.

C. Max Bauer	G. C. Gester	R. E. Somers
S. P. Borden[1]	S. A. Grogan	H. A. Stewart
M. G. Cheney	R. F. Imbt	Willis Storm
Glenn C. Clark	R. S. McFarland	A. C. Trowbridge
David Donoghue	H. D. Miser	A. F. Truex
A. W. Duston	Earl B. Noble	John M. Vetter
J. E. Elliott	C. M. Rath	H. J. Wasson
H. B. Fuqua	R. J. Riggs	S. H. Woods

[1]Representing W. E. Hopper.

International Geological Congress

Mr. Wrather offered the following motion:

Moved, that this Association join with other scientific societies of the United States in an invitation to the 16th International Geological Congress to meet in the United States in 1932, and that the Association members do what they can for the success of the project.

The motion carried unanimously.

San Antonio Section

President McFarland presented the recommendation of the executive committee that the petition of the San Antonio Geological Society be accepted and that the San Antonio section of the A. A. P. G. be chartered.

The recommendation was unanimously adopted, and the executive committee authorized to charter the section.

The committee on elections reported.

Report of Annual Elections

Nominations for officers of the Association were made in open meeting, Thursday afternoon, the first day of the meeting. Ballot boxes were open all day Friday. Total ballots cast, 466.

For president,	J. Y. Snyder,	244
	F. W. DeWolf,	222
For 1st vice-president,	F. H. Kay,	255
	E. F. Schramm,	201
For 2d vice-president,	A. R. Denison,	234
	W. R. Hamilton,	223
For 3d vice-president,	F. H. Lahee,	281
	C. W. Tomlinson,	182

C. P. Watson, *chairman*

S. P. Borden
M. W. Grimm

John M. Vetter
W. B. Wilson

The meeting was adjourned at 11:30 A. M.

David Donoghue, *2d vice-president*

AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

The Shreveport Geological Society will hold its ninth annual field trip on June 7, 8, and 9, through southwestern Tennessee, northwestern Alabama, and northeastern Mississippi. The trip will cover the Eocene, Cretaceous, and Paleozoic, down to, and including, the Knox dolomite. The field trip party will leave the Union Station at Memphis, Tennessee, on Friday, June 7, at 9 A. M., and will travel by bus only. The first night will be spent at Columbia, Tennessee, the second night at Muscle Shoals, Alabama, and the return will be made to Memphis, Sunday, at 8 P. M. It will be positively necessary for everyone deciding to make this trip to make reservations and deposit $10.00, which will cover bus fare only for the trip, with M. W. Grimm, 315 Ward Building, Shreveport, Louisiana, not later than June 1, 1929. Due to the activities now commencing and going on in western Tennessee, Mississippi, and Alabama, this will be a very interesting trip. The section covered will include everything that will be found in later drilling. It is hoped to have as many on the trip as can possibly arrange to go.

The National Association of Consulting Geologists was organized at San Angelo, Texas, March 16, with ROBERT B. CAMPBELL as president. V. E. COTTINGHAM was named vice-president, ROBERT IMBT, secretary, and ROBERT L. CANNON, treasurer. Any geologist actively engaged in consulting geological practice is eligible to membership in the organization, provided he is a member of the American Association of Petroleum Geologists, or the American Institute of Mining and Metallurgical Engineers, or the Geological Society of America. The second meeting was held at Fort Worth during the convention of the American Association of Petroleum Geologists, March 21-23.

R. F. BAKER, chief geologist for The Texas Company, has moved his headquarters from Houston, Texas, to New York City.

R. A. RANK has gone to Venezuela for two years with the Creole Petroleum Corporation. His address is Apartado 85, Maracaibo.

W. T. NIGHTINGALE has left Casper to take charge of the geological department of the newly organized Mountain Fuel Supply Company at Rock Springs, Wyoming.

N. W. BASS has been placed in charge of the Kansas geological work of The Pure Oil Company, with headquarters at 205 South Belmont Avenue, Wichita, Kansas.

W. S. LEVINGS is torsion-balance troop leader with the Gulf Oil Corporation in Colombia, South America.

HERBERT H. KISTER, of the Dixie Oil Company, Inc., has been transferred from Enid to Shawnee, Oklahoma, to take charge of the Seminole-Oklahoma City area.

The women geologists at the Fort Worth meeting of the A. A. P. G. held a special meeting of their own for the purpose of becoming better acquainted, and appointed the following committee to arrange for organization and mutual assistance at next year's convention: ALVA C. ELLISOR, chairman, Humble Oil and Refining Company, Houston, Texas; CONSTANCE G. EIRICH, vice-chairman, Gypsy Oil Company, Tulsa, Oklahoma; and ELLEN POSEY, secretary-treasurer, University of Oklahoma, Norman, Oklahoma.

Mr. and Mrs. A. E. CHEYNEY of Russell, Kansas, announce the birth of Wade Kent, April 3, 1929.

R. S. MCFARLAND, formerly secretary and superintendent of the land and geological department of The Twin State Oil Company, is now vice-president in charge of land and geological departments of the Sunray Oil Company, with offices at 1404 Exchange National Bank Building, Tulsa, Oklahoma.

JOHN P. SMOOTS and Miss Cleo Roquemore of Shreveport, Louisiana, were married April 2, 1929. Their home is at 2664 North Moreland Boulevard, Cleveland, Ohio.

FRANK A. HERALD is general manager of Westbrook-Thompson Holding Corporation, 1404 Electric Building, Fort Worth, Texas.

W. G. WENDER, formerly with the Amerada Petroleum Corporation at Cisco, Texas, is associated with J. A. MacDonnell, independent operator of Lima, Ohio. Mr. Wender will maintain headquarters at Cisco.

E. DEGOLYER, for some years president, has been elected chairman of the board of the Amerada Corporation, New York City. Mr. DeGolyer is now particularly active in geophysical methods of oil prospecting through the Amerada subsidiary, the Geophysical Research Corporation.

MARION H. FUNK is with the American Oil and Refining Company, Skirvin Hotel, Oklahoma City, Oklahoma.

ALEX W. MCCOY is vice president of the newly organized E. W. Marland Company, Inc., at Ponca City, Oklahoma.

THE SECOND INTERNATIONAL DRILLING CONGRESS will be held in Paris, September, 1929. Those interested should address the Congress, Boul. Montparnasse, Paris VI-e, France.

JAMES TERRY DUCE, formerly consulting geologist, attached to the New York office of The Texas Company, has been appointed manager of the Texas Petroleum Company, a subsidiary of The Texas Company, operating in Venezuela and Colombia.

FRED C. SEALY, division geologist in the Wichita Falls district of The Texas Company, has been appointed assistant manager of the South Texas division of the same company, with headquarters at Houston.

R. S. POWELL has been appointed division geologist of the Wichita Falls district of The Texas Company, succeeding FRED C. SEALEY, who has been transferred to other duties.

GEORGE W. SCHNEIDER has been appointed division geologist of the Louisiana-Arkansas division of The Texas Company, succeeding F. J. MILLER who resigned from the service of The Texas Company.

PROFESSIONAL DIRECTORY

SPACE FOR PROFESSIONAL CARDS IS RESERVED FOR ACTIVE MEMBERS OF THE ASSOCIATION. FOR RATES, APPLY TO THE BUSINESS MANAGER, BOX 1852, TULSA, OKLAHOMA

DIRECTORY OF GEOLOGICAL SOCIETIES

FOR THE INFORMATION OF GEOLOGISTS VISITING LOCAL GROUPS. FOR SPACE, APPLY TO THE BUSINESS MANAGER, BOX 1852, TULSA, OKLAHOMA

PANHANDLE GEOLOGICAL SOCIETY

AMARILLO, TEXAS

PRESIDENT - - - - - - - L. R. HAGY
HAGY, HARRINGTON & MARSH

VICE-PRESIDENT - - - - - - L. M. OLES
PRAIRIE OIL & GAS COMPANY

VICE-PRESIDENT - - - - - - W. L. DAY
DELMAR OIL COMPANY

SECRETARY-TREASURER - - HENRY ROGATZ
PHILLIPS PETROLEUM COMPANY

MEETINGS: FIRST AND THIRD FRIDAY NOONS EACH MONTH. PLACE: LONG HORN ROOM, AMARILLO HOTEL

NORTH TEXAS GEOLOGICAL SOCIETY

WICHITA FALLS, TEXAS

PRESIDENT - - - - - WARD C. BEAN
SHELL PETROLEUM CORPORATION

VICE-PRESIDENT - - - - J. B. LOVEJOY
GULF PRODUCTION COMPANY

SECRETARY-TREASURER - - F. K. FOSTER
SINCLAIR OIL & GAS COMPANY

MEETINGS: SECOND AND FOURTH SATURDAYS EACH MONTH, AT 6:30 P. M.
PLACE: WICHITA CLUB, CITY NATIONAL BANK BLDG.

Tulsa Geological Society

TULSA, OKLAHOMA

PRESIDENT - - - - - - A. I. LEVORSEN
INDEPENDENT OIL & GAS COMPANY

1ST VICE-PRESIDENT - - H. E. ROTHROCK
SUPERIOR OIL COMPANY

2ND VICE-PRESIDENT - - HARRY H. NOWLAN
620 WORLD BLDG.

SECRETARY-TREASURER - WILLIAM W. KEELER
MINNEHOMA OIL COMPANY

MEETINGS: FIRST AND THIRD MONDAYS EACH MONTH, AT 8:00 P. M., FOURTH FLOOR, TULSA BUILDING. LUNCHEONS: EVERY THURSDAY, FOURTH FLOOR, TULSA BUILDING.

The Shreveport Geological Society

SHREVEPORT, LOUISIANA

PRESIDENT - - - - - - S. P. BORDEN
CONSULTING GEOLOGIST,
ROOM 621, ARDIS BLDG.

VICE-PRESIDENT - - - GEORGE BELCHIC
BELCHIC & LASKEY
SLATTERY BLDG.

SECRETARY-TREASURER - - W. F. CHISHOLM
MINERALS DIVISION,
DEPT. CONSERVATION, WARD BLDG.

MEETS THE FIRST FRIDAY OF EVERY MONTH, ROOM 605, SLATTERY BUILDING. LUNCHEON EVERY MONDAY NOON, WASHINGTON HOTEL.

Dallas Petroleum Geologists

DALLAS, TEXAS

CHAIRMAN - - - - - - F. E. HEATH
SUN OIL CO.

VICE-CHAIRMAN - - - - - H. B. HILL
U. S. BUREAU OF MINES

SECRETARY-TREASURER - KARL H. SCHILLING
SHELL PETROLEUM CORP.

MEETINGS: ALTERNATE MONDAYS, 6:00 P. M., USUALLY AT BAKER HOTEL. VISITING GEOLOGISTS ALWAYS WELCOME AND URGED TO ATTEND. ADDITIONAL INFORMATION ON MEETINGS BY CALLING SECRETARY.

Geological Society of Northwestern Oklahoma

ENID, OKLAHOMA

PRESIDENT - - - - - BASIL B. ZAVOICO
CONSULTING GEOLOGIST, 501 PHILTOWER, TULSA

VICE-PRESIDENT - - - - - CARL S. FORD
ENID BANK & TRUST BUILDING

SECRETARY-TREASURER - - J. H. VAN ZANT
HEALDTON OIL & GAS COMPANY

MEETINGS: FIRST SATURDAY OF EACH MONTH, AT 6:30 P. M. IN THE OXFORD HOTEL GRILL. ALL VISITING GEOLOGISTS ARE WELCOME.

Kansas Geological Society

WICHITA, KANSAS

PRESIDENT - - - - - JOHN R. REEVES
EMPIRE OIL & REFINING CO.
OIL HILL, KANSAS

VICE-PRESIDENT - RICHARD B. RUTLEDGE
BARNSDALL OIL COMPANY

SECRETARY-TREASURER - ANTHONY FOLGER
GYPSY OIL COMPANY

REGULAR MEETINGS 12:30 P. M., AT INNES TEA ROOM, THE FIRST SATURDAY OF EACH MONTH. VISITING GEOLOGISTS ARE WELCOME.

THE KANSAS GEOLOGICAL SOCIETY SPONSORS THE WELL LOG BUREAU WHICH IS LOCATED AT 719-20 UNION NATIONAL BANK BUILDING.

Houston Geological Society

HOUSTON, TEXAS

PRESIDENT - - - - - - PAUL WEAVER
GULF PRODUCTION COMPANY

VICE-PRESIDENT - - - - - JOHN M. VETTER
SECOND NATIONAL BANK BUILDING

SECRETARY-TREASURER - - MARCUS A. HANNA
GULF PRODUCTION COMPANY

REGULAR MEETINGS EVERY TUESDAY AT NOON AT THE RICE HOTEL. FREQUENT SPECIAL MEETINGS CALLED BY THE EXECUTIVE COMMITTEE. FOR ANY PARTICULARS PERTAINING TO MEETINGS CALL THE SECRETARY.

West Texas Geological Society

SAN ANGELO, TEXAS

PRESIDENT - - - - - V. E. COTTINGHAM
COTTINGHAM AND BRISCOE

VICE-PRESIDENT - - - - - A. L. ACKERS
SOUTHERN CRUDE OIL PURCHASING CO., MIDLAND

SECRETARY-TREASURER - - STANLEY E. JAY
PURE OIL COMPANY

MEETINGS: FIRST SATURDAY EACH MONTH AT 7:30 P. M., ST. ANGELUS HOTEL. LUNCHEON: THIRD SATURDAY EACH MONTH AT 12:15.

Rocky Mountain Association of Petroleum Geologists

PRESIDENT - - - - - JOSEPH S. IRWIN
CONSULTING GEOLOGIST
935 ST. PAUL STREET

VICE-PRESIDENT - - CHAS. S. LAVINGTON
CONTINENTAL OIL COMPANY

VICE-PRESIDENT - - J. HARLAN JOHNSON
COLORADO SCHOOL OF MINES
GOLDEN, COLORADO

SECRETARY-TREASURER - W. A. WALDSCHMIDT
MIDWEST REFINING COMPANY

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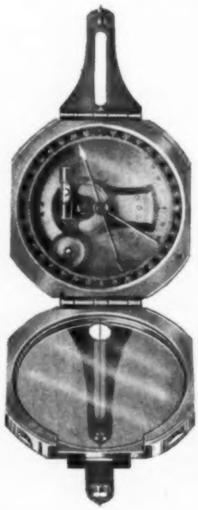

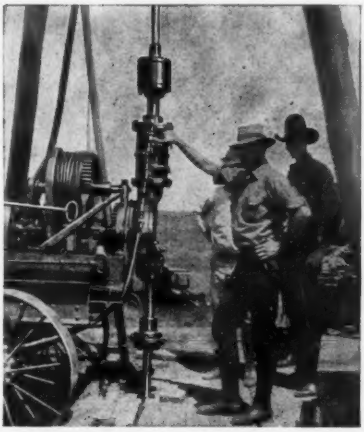

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